PHYSICS ASSEMBLY LABORATORY
(Physics Assembly Laboratory, Building No. 777-M)
(Building No. 777-10A)
Area A/M, Savannah River Site
Aiken
Aiken
South Carolina

HAER SC-43
SC-43

PHOTOGRAPHS

WRITTEN HISTORICAL AND DESCRIPTIVE DATA

FIELD RECORDS

HISTORIC AMERICAN ENGINEERING RECORD
SOUTHEAST REGIONAL OFFICE
National Park Service
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HISTORIC AMERICAN ENGINEERING RECORD

PHYSICS ASSEMBLY LABORATORY

(Physics Assembly Laboratory, Building No. 777-M)
(Physics Assembly Laboratory, Building No. 777-10A)

HAER NO. SC-43

Location:	Area A/M, Savannah River Site, formerly Savannah River Plant, Aiken Vicinity, Aiken County, South Carolina; USGS New Ellenton SW, SC Quadrangle Universal Transverse Mercator Coordinates: Zone 17, 431593E, 3688751N
Date of Construction:	1952-53
Architect:	Voorhees Walker Foley & Smith
Builder:	E. I. du Pont de Nemours and Company
Present Owner:	U.S. Department of Energy
Present Use:	Demolished
Significance:	The Physics Assembly Laboratory, a testing facility at the Savannah River Plant that housed a zero power reactor known as the Process Development Pile, is significant for its role in establishing the physics parameters for plutonium and tritium production in five Cold War era heavy water moderated and cooled production reactors. Savannah River Plant was constructed by the Atomic Energy Commission between 1950 and 1956 for the production of nuclear materials for the nation's arsenal. Beyond this historically important defense mission, the Physics Assembly Laboratory's test reactors were used for physics experiments until computers made their research potential obsolete in 1979.
Report Prepared By:	New South Associates and Washington Savannah River Company
Date:	2006

PART I. HISTORICAL INFORMATION

A. INTRODUCTION

This narrative details the historical development of the Physics Assembly Laboratory, best known to its users by the building number designation, 777-M, or colloquially as "Triple 7." As it was normally identified by building number rather than the formal name, this narrative will follow suit. Building No. 777-M was located at the Savannah River Site (SRS), first known as the Savannah River Plant (SRP), in Aiken County, South Carolina. The SRP, a major site within the nation's production complex, was constructed by the Atomic Energy Commission (AEC) to produce nuclear materials. Five heavy water moderated production reactors, one-third of the production reactors that have ever been constructed in the United States, were built at the South Carolina site to produce plutonium and tritium for the nation's nuclear arsenal. Moreover, the SRP reactors were the first heavy water reactors to be built in the nation for production purposes.

The experimental reactors in Building No. 777-M played an important role in the operation of these production reactors, particularly in the early months before the first production reactor, R Reactor, went critical in late December of 1953. In the summer and fall of 1953, the experimental reactors in 777-M were essential for the study of the Savannah River production reactor design and operation, as well as for the calibration of various standards and monitoring devices required by the reactors.[1] Even though this was the most important of the many uses of 777-M over the years, the building and its experimental reactors were associated with almost every major aspect of the use and improvements made to the Savannah River production reactors, from 1953 until the basic perfection of the production process in the 1970s.

SRS was divided into different areas of operation, such as reactors areas, separations areas, fuel and target fabrication, heavy water production, and administration. Each area was

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[1] E. I. Du Pont de Nemours and Company, *Savannah River Plant Engineering and Design History, Volume IV of VI; 300/700 Areas and General Services and Facilities*, Engineering Department, Wilmington, Delaware, Prime Contractor for United States Atomic Energy Commission, U.S. Contract AT(07-2)-1, Du Pont Project 8980, January 1957, 13.

assigned a unique number based on function, as well as a letter designation. Reactor areas were designated 100 areas, with each of the five production reactor areas also assigned a specific letter (100-R, P, L, K, and C). The same was true for the two separations areas (200-F and 200-H). There was only one fuel and target fabrication area (300/M Area), just as there was only one administration area (700/A Area). This administration area also included the main buildings of the Savannah River Laboratory, now identified as the Savannah River National Laboratory (SRNL). Both M and A areas were situated together at the northern edge of the plant. Building No. 777-M was located at the southwest end of the 300/M Area.

For most of its existence, Building No. 777-M was controlled and operated by the Savannah River Laboratory (SRL), which oversaw the physics required in the operation and improvements to the production reactors. For this reason, the Physics Assembly Laboratory was identified as 777-M, reflecting its ties to both the 700-Area and SRL, and to M-Area, dedicated to manufacturing fuel and target elements. This designation suggests the uniqueness of the building and its function. In fact, the building kept this designation until the early 1980s, when a change in mission required a change in the designation, from 777-M to 777-10A. At that time, reactor work was phased out, and much of the building was adapted for audio-visual work at Savannah River.

In the early years, however, 777-M was known as the home of Savannah River's experimental reactors. By the 1970s, Building No. 777-M had a total of five experimental reactors: the Process Development Pile (PDP); the Standard Pile (SP); the adjoining Exponential Pile or Subcritical Experiment (SE), the Pressurized Exponential Pile (PSE); and the Resonance Test Reactor (RTR), later renamed the Lattice Test Reactor (LTR). The most important of these, however, were the first three: the Process Development Pile (PDP) and the SP and SE (the last two usually operated together). Of these three, the PDP, a full-scale nuclear mock-up of the heavy water moderated production reactors at Savannah River, was the most significant. The PDP provided researchers with the opportunity to study the physics of the production reactors and their fuel and target assemblies without having to impede production, and without the radiation problems associated with the production reactors.[2]

B. CONTEXT

Building Design and Construction History

The design and construction of Building No. 777-M was part of the much larger design and construction program for all of Savannah River Plant, which was conceived, designed, and constructed between 1950 and 1956. This work, completed for the AEC, was the responsibility of the E. I. du Pont de Nemours and Company (referred to after this as "Du Pont") and its many subcontractors. Most of this work, certainly all of it until at least 1954, was part of what was formally known as "Du Pont Project 8980." The work force for Project 8980 peaked in September of 1952 with 38,582 employees. Project 8980 continued until 1956, when the first wave of construction was completed. Construction of new facilities, of course, continued in the years to follow, and beginning in 1954, this new work was designed and built as individual projects, as the need for new construction arose. Such projects were designated supplemental projects or "S" Projects, and were usually performed by the Du Pont Engineering Department.[3]

Building Design Work

Building No. 777-M, one of the first buildings constructed at Savannah River, was an experimental physics facility. With the PDP, Building No. 777-M could determine the nuclear properties of the elements within a functioning reactor. It was the intermediate step between the theory of how a heavy water moderated reactor should work, and the actual working of such a reactor. The antecedents of the Savannah River reactors will be described in the following section of the report, but it is

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[2] Ibid., 130; G. Dessauer, K. H. Doeringsfeld, and E. C. Toops, "Design Data Report, Revised, Project 8980 – Savannah River Plant, Pile Physics Laboratory, Building 777-M," Explosives Department, Atomic Energy Division, E. I. Du Pont de Nemours and Company, September 4, 1952, 10.

[3] E. I. Du Pont de Nemours and Company, *Savannah River Plant Engineering, Design, and Construction History of "S" Projects and Other Work, November 1953 to December 1960,* Engineering Department, Wilmington, Delaware, Prime Contractor for United States Atomic Energy Commission, U.S. Contract AT(07-2)-1, December 1963, 13; *Facts Book, Savannah River Plant, 1953*, History Section, Engineering Office Department, Savannah River Plant, 1953, 16.

important to note that no production reactors in the United States had ever been run with a heavy water moderator.[4] All earlier production reactors used graphite as the moderator. While it was certainly known that a heavy water reactor could work, there were many operational details that had to be worked out. While other newly constructed SRP facilities contributed mechanical and engineering knowledge to that end, the experimental reactors in Building No. 777-M would finesse the nuclear physics side of the problem.

First Building Concepts

In 1951, when the first design plans for Building No. 777-M were formulated, it was not certain where the building was going to be sited. The first tentative layout of the 300/700 Area was made in February of 1951. The following month, the entire area was relocated to what is now its current location.[5] When 777-M was mentioned in the first design data report, on July 30, 1951, the building was designated "777-A," since it was originally thought to locate it adjacent to the Savannah River Laboratory. This location was still current at the time of the second design data report, dated October 1951. By that time, Du Pont engineers had basically outlined the size of the building itself, and had specified room sizes and services.[6]

Building No. 777 was removed from the 700-A Area to the 300-M Area in early November of 1951. This mandated a switch in the building designation from "777-A" to "777-M." At that time, it was decided to place the building at the south end of M Area, where it would not require an extra gatehouse.[7]

In the early days of 1951, when Building No. 777-M was nothing more than a concept, there was some discussion about whether to make the building a Class I, II, or III construction. These

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[4] A substance, such as water or graphite, that is used in a nuclear reactor to decrease the speed of fast neutrons and increase the likelihood of fission.

[5] Voorhees Walker Foley and Smith, *Savannah River Plant Engineering and Design History, Volume I of II, Text and Exhibits*, New York: Voorhees Walker Foley and Smith, Subcontractor for Engineering Department, E. I. Du Pont de Nemours and Company, Wilmington, Delaware, Prime Contractor for United States Atomic Energy Commission, U.S. Contract No. AT(07-2)-1, Du Pont Project 8980, Subcontract No. AXC-6-1/2, December 1, 1953, 172-173.

[6] Dessauer et al., "Design Data Report," 8.

[7] Voorhees Walker Foley and Smith, *SRP Engineering and Design History, Vol. II*, 156; Dessauer et al., "Design Data Report," 8.

classes constituted a building code created by Du Pont for SRP construction, keyed to the use of building materials that would enable a building to withstand a "blast." Class I was considered "blast resistant construction," with reinforced concrete walls and a roof of steel or concrete frames. Class II was "friable construction," where the building frame would be substantial concrete or steel construction, but the exterior walls would be covered with a friable material (usually flat cement asbestos, or Transite™) that would be expendable in a blast. Class III, "normal construction," called for steel framing with corrugated or flat cement asbestos siding.[8]

At first, it was thought appropriate to make 777-M a Class I construction. This determination was based on the importance of the work in 777-M, and because reinforced concrete would be required anyway in much of the building, especially around the reactors. Later, in November 1951, in order to save money, it was decided to make it Class III, with shielding walls only where it was needed.[9]

Up to this point, Du Pont's Technical Division of the Atomic Energy Division (AED) of the Explosives Department, as well as the Design and Development Engineering Divisions of the Engineering Department, and the Process Section of the Manufacturing Division had completed most of the conceptual work on 777-M.[10] The first general specifications for the PDP had been worked out by both the Design Division and the AED.[11] In late 1951, however, Du Pont began to share this work with three of its major Savannah River subcontractors: Voorhees Walker Foley and Smith (VWF&S), New York Shipbuilding Corporation, and American Machine and Foundry Company (AM&F). VWF&S worked on the building plans and the overall process. New York Shipbuilding fabricated the PDP reactor tank, while AMF was generally limited to work on specific pieces of equipment. In the end, VWF&S did all the final design and drawings for the building and ninety percent of the instrument and electrical drawings, including much of the design work for the PDP.[12]

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[8] Voorhees Walker Foley and Smith, *SRP Engineering and Design History, Vol. I*, 68-71.
[9] Voorhees Walker Foley and Smith, *SRP Engineering and Design History, Vol. II*, 156; Du Pont, *SRP Engineering and Design History*, Vol. IV, 144.
[10] Dessauer et al., "Design Data Report," 8-9.
[11] Du Pont, *SRP Engineering and Design History*, Vol. IV, 149.
[12] Ibid., 160.

VWF&S, an architectural and engineering firm based in New York City with strong experience in laboratory design, had just finished some design work at Argonne National Laboratory prior to Savannah River. The firm had also worked for Du Pont at the Dana Plant in Indiana. As a result, VWF&S already had a large number of technical people with the requisite AEC clearances. VWF&S was invited to become one of Du Pont's subcontractors on the Savannah River project as early as November and December of 1950. The general scope of work was defined in a letter from Du Pont, dated June 20,1951, but marked effective as of December 31, 1950. This letter became the basis of the subcontract, which was amended throughout the history of Du Pont's Project 8980. This contract entailed a huge amount of work, and it soon included Building No. 777-M.[13]

VWF&S was asked to work on the design of 777-M in early October 1951, even before the final determination of the building's location and construction class. This led to the first serious plan of the building, labeled Sketch No. 1, dated to October 19, 1951. At that time, the arrangement of the building reactors had not yet been finalized. Greater details were provided in "Sketch No. 4, Main Floor Plan," dated to November 28, 1951. The first revised elevations and wall section sketches were submitted to Du Pont on December 5, 1951. On January 4, 1952,Du Pont gave VWF&S authority to proceed with working drawings of the building.[14]

To prepare the working drawings, VWF&S relied on basic information provided by the Design Division of Du Pont's Engineering Department, usually supplied in Design Data transmittal forms and reports. There were also regular meetings between the two firms. Whenever possible, use was made of Du Pont's engineering and design standards, which emphasized modular planning whenever possible. VWF&S also had to coordinate its work with the other two subcontractors working on the building, New York Shipbuilding and American Machine and Foundry.[15]

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[13] Voorhees Walker Foley and Smith, *SRP Engineering and Design History, Vol. I*, 1-4, 9.
[14] Ibid., 130-131, 175; Voorhees Walker Foley and Smith, *SRP Engineering and Design History, Vol. II*, 156.
[15] Voorhees Walker Foley and Smith, *SRP Engineering and Design History, Vol. I*, 10-11, 47-50.

The first full set of preliminary plans for all levels of the building, basically identified as Sketches Nos. 8 through 22 were submitted by VWF&S in early 1952, and were returned by Du Pont on February 5, 1952. These sketches formed the basis of the working drawings that were prepared next.[16] Unlike the sketches, which were labeled "Sk," the working drawings, labeled "W," would be more or less the finished plans, and basis for what was actually built. The final working drawings were prepared in New York, and in the case of Building No. 777-M and the PDP, this required a total of sixty-five drawings, which did not include all of the piping, ventilation, instrumentation, and electrical work. Design work for the exponential pile (SE) required another eleven drawings.[17]

The majority of the design work for 777-M revolved around the requirements of the PDP. Du Pont provided preliminary sketches for the piping and equipment plans in late 1951 through early 1952. VWF&S developed these plans by May of 1952. By this time, the building foundation plans had also been completed. The following month, in June of 1952, VWF&S began to coordinate its work with New York Shipbuilding in the design of the reactor tank. Design work on the Exponential tank (SE) was one of the last to be done, in January of 1953.[18]

The final process drawings for Building No. 777-M were completed between late 1952 and early 1953, with the last details of the laboratory arrangements and instruments completed in January of 1953.[19] In addition to these plans, VWF&S also prepared perspective drawings for 777-M. An actual model of 777-M, rendered in paper, balsa wood and plastic, was submitted to Savannah River on January 20, 1953. Built at a scale of three-eighths of an inch to one foot, the model measured 36" x 40" x 42", representing a space comparable to 80'-0" x 90'-0" x 100'-0".[20] The model is presently curated at SRS.

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[16] Voorhees Walker Foley and Smith, *SRP Engineering and Design History, Vol. II*, 156-157.
[17] Voorhees Walker Foley and Smith, *SRP Engineering and Design History, Vol. I*, 130-131.
[18] Voorhees Walker Foley and Smith, *SRP Engineering and Design History, Vol. II*, 157; *Vol. I*, 175.
[19] Voorhees Walker Foley and Smith, *SRP Engineering and Design History, Vol. II*, 158.
[20] Voorhees Walker Foley and Smith, *SRP Engineering and Design History, Vol. I*, 134-139, 175.

Final Design Results

As represented in the final plans, Building No. 777-M housed the PDP that was capable of great flexibility. This was essential in a reactor that would be used to test different reactor operation techniques and designs. The reactor also came equipped with the full range of shielding, control room instrumentation, storage, and lab space.

Considerable thought was given to both safety issues and to operational efficiency. The concrete shielding around the PDP and the SP was between five and six feet thick. The reactors themselves were situated below ground level for extra protection. All openings in the shielding walls were at least seven feet above ground level to provide added protection for the operators. "PDP On" and "SP On" signs throughout the building warned workers when the reactors were in operation. If a door opened in the middle of operation, a safety circuit would shut down the reactors.

Shielding was also provided in the laboratory wing "counting room" to allow for instrument accuracy, and to limit disturbance from both the 777-M reactors and from the graphite reactor in 305-M. Otherwise, the laboratory wing was provided with limited shielding, since none of the reactors in the area would ever be operated at high levels of radiation. Most of the lab wing design was based on a simplified version of those used for Building No. 773-A, the main SRL building. In addition to the men's locker and shower rooms, emergency showers were located beside the chemistry lab and the shop. Special consideration was also given to fire protection, since no water could be used, due to the presence of both nuclear fuel and heavy water. Carbon dioxide hand extinguishers were situated in the reactor rooms and the assembly and disassembly rooms; in addition, there was other fire fighting equipment.[21]

One of the auxiliary features of the building, though an important one, was air conditioning. This provided protection for the moderator, since air conditioning would limit the amount of light water contamination that might occur through moisture condensation or light water vapor.[22] Consideration was also

[21] Du Pont, *SRP Engineering and Design History*, Vol. IV, 143-146.
[22] Dessauer et al., "Design Data Report," 60.

given to the nature of the lighting. The labs and offices were set up with fluorescent lights, while the nuclear physics lab, the counting room, and the neutron beam room were equipped with incandescent bulbs. Originally, it was thought that fluorescent lighting in the nuclear lab areas would interfere with the electronic equipment needed to record the nuclear measurements. This proved not to be the case, but the final design reflected this original line of thought.[23]

Building Construction

Construction began on February 2, 1952, almost immediately after the final plans were approved. By the end of that month, the construction site was a large excavation pit in what would soon be the PDP reactor area. By April of 1952, the sub-basement was under construction, and by May and June, the basement level. In July, work began on the aboveground phase of construction. By October of 1952, the exterior shell of the building had been completed, at least in the vicinity of the Reactor Wing. The Lab Wing steel frame went up, beginning in October 1952. By March of 1953, the exterior of the building had basically been finished.[24]

Operations personnel occupied the reactor wing of the building on April 13, 1953. The lab and office areas were occupied on June 1, 1953. The completed building was formally accepted by Operations from Construction on July 5, 1953. Among the materials used in the construction were 5,175 cubic yards of concrete; 315 tons of reinforced steel; 400 tons of structural steel; and 89,600 square feet of asbestos (Transite™) siding. At the beginning of construction, the building was slated to have two experimental reactors: the PDP, a mock-up of the production reactors; and the SP, a test reactor used for calibrations and as a source for neutrons for experiments. It was only later that the SE, an exponential facility later considered a reactor in its own right, was added on top of the SP. According to the SRL Director Milton Wahl, this addition of

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[23] Du Pont, *SRP Engineering and Design History*, Vol. IV, 146.
[24] E. I. Du Pont de Nemours and Company, *Savannah River Plant Construction History, Volume IV of IV; Construction, 300-M, 400-D, 700-A, and 500/600/900-G Areas,* Engineering Department, Wilmington, Delaware, Prime Contractor for United States Atomic Energy Commission, U.S. Contract AT(07-2)-1, Du Pont Project 8980, January 1957, 145; Information based on construction photographs on file at SRS Archival Records.

the SE was decided upon when the construction of 777-M was "well underway."[25]

As a result of all this work, Building No. 777-M was intact and functioning as an experimental facility by the late spring, early summer of 1953. At that time, it was formally described as a Class III structure having an "L" shape. The reactor wing measured 129'-0" x 83'-0", with a total vertical measurement of sixty feet divided into various levels. The laboratory wing measured 52'-0" x 146'-0", with a ground level story and a full basement. The building rested on reinforced concrete mat footings and spread footings. There was a structural steel framework supporting most of the building. The roof was comprised of reinforced concrete roof slabs, supported by steel beams, in the high section of the reactor wing, and rib lath in the remainder. The exterior walls were covered with flat cement asbestos board or Transite™, affixed to steel beams.[26]

Even though 777-M had been built at some distance from the SRL, it was still very much a facility of the SRL. This was not always apparent in the early days only because the SRL was not organized until July of 1952, with Milton H. Wahl as the first laboratory director. Before that time, Du Pont's Technical Division did most of the local experimental work, with personnel answerable to bosses at Du Pont's main office in Wilmington, Delaware. By 1953, however, Building No. 777-M was established as one of the key facilities of the SRL, along with the Main Technical Laboratory, the Waste Disposal Facility (776-A), and the CMX-TNX complex.[27] It is interesting to note that during this period, and for many years to come, the SRL had no direct organizational ties to Savannah River Plant. All liaisons with the plant went back up through Wilmington within the Du Pont organization.

In June of 1953, when Building No. 777-M was just completed, the SRL was reorganized with the arrival of Charles W. J. Wende from Wilmington, and J. W. Morris from the Dana Plant in Indiana. Two separate laboratory sections were created: the "Pile

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[25] Du Pont, *SRP Construction History*, Vol. IV, 145; Milton H. Wahl, "History, Savannah River Laboratory, June 1951 to June 30, 1953," E. I. Du Pont de Nemours and Company, Explosives Department – Atomic Energy Division, Technical Division – Savannah River Laboratory, Augusta, Georgia, 1954, 6.
[26] Du Pont, *SRP Construction History*, Vol. IV, 144.
[27] Wahl, "History, Savannah River Laboratory," 4, 6.

Technology and Materials Section," under Wende; and the "Separations Technology and Laboratory Services Section," under Morris. Building No. 777-M was run by Pile Technology.[28] Within this umbrella, 777-M was soon administered by the Laboratory's Experimental Physics Division. By this time, it had been determined that the main purpose of the SRL was to support the operation of the plant. It was thus established that the reactor personnel at SRL had to work together with their closest counterparts at the plant: the people within "Reactor Technology."[29]

Equipment Design and Construction

Building No. 777-M was basically a shell surrounding the two experimental reactors, the PDP and the SP (the SE was generally considered part of the SP in the early 1950s). Even though the PDP and the SP did not normally work in tandem, their operations were clearly complementary. The PDP provided the larger picture of the nuclear activity that took place within a Savannah River production reactor. This was done through the different arrangement of elements that went into the reactor, and from the different arrangements of those elements within a framework called a "lattice." The SP and SE worked on a smaller scale, examining the nuclear properties of individual elements or small groups of elements.

The design and construction of the PDP was clearly the most important of the two test reactors. Due to its integral role in SRP reactor design, its criticality preceded the startup and operational life of the full-scale heavy water-moderated reactors at SRP, establishing the PDP as the nuclear precursor to R Reactor, the first of the production reactors. If the Savannah River production reactors were experimental, compared to the first generation of older graphite reactors at Hanford, then the PDP was doubly so. It had ties to the large graphite reactors inherited from the Manhattan Project, but its immediate predecessors were the small heavy water moderated experimental reactors constructed at Argonne in the late 1940s and early 1950s.

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[28] Ibid., 10.
[29] Tom Gorrell, personal communication, January 30, 2006; Norm Baumann, personal communication, October 19, 1999.

Precursors to the PDP

The reactors at Hanford, in Washington State, constructed for the Manhattan Project, were the first production reactors anywhere in the world. The Hanford complex was still in operation at the time of the design and construction of Savannah River, but these reactors were moderated with graphite blocks piled into what looked like a structure. The earliest name for a nuclear reactor, the word "pile," came from this, and was actually the preferred term for a reactor until the mid-1950s.

One of the legacies of the Manhattan Project was the use of graphite reactors for the production of fissionable material. Graphite, however, was not the best material for the moderation of thermal neutrons. Even in the days of the Manhattan Project, it was known that heavy water had better moderation properties. It slowed neutrons quicker than graphite, and it absorbed fewer, leaving more to serve production needs. Unlike graphite, it could simultaneously serve as both moderator and coolant. During World War II, however, the problem with heavy water was supply. There was not enough to do the job.[30]

Even in the years that followed, heavy water was difficult to produce or harvest. Heavy water is found naturally in regular "light" water only at the rate of 1 per 5,000 atoms. Much of the heavy water used at Savannah River was produced on site, in the 400-D Area, by means of the hydrogen-sulfide dual temperature exchange process known as the "GS process." It has been estimated that the heavy water within the PDP system alone cost around $12 million.

Because Savannah River reactors were to be moderated with heavy water, nuclear engineers with the AEC and Du Pont did not draw direct inspiration from the Hanford reactors, but rather from the smaller heavy water-moderated reactors at Argonne National Laboratory, the AEC's center for reactor research, then located near Chicago, Illinois.

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[30] Richard G. Hewlett and Francis Duncan, *Atomic Shield, 1947 / 1952: Volume II, A History of the United States Atomic Energy Commission* (University Park: Pennsylvania State University Press) 1969, 429; Norm Baumann, personal communication, October 19, 1999; Peter Gray, personal communication, October 13, 1999; Fact Book, Savannah River Plant, Office of Public Education — Public Information, Savannah River Operations Office, US Atomic Energy Commission, Aiken, South Carolina, 1960, 12.

By the early 1950s, graphite reactors and their operation posed no mysteries. In fact, the very first reactor to operate at Savannah River was the graphite test pile in 305-M, which went critical in September of 1952 and was in operation testing fuel metals before the end of the year.[31] Relatively little fanfare accompanied this achievement.

The Savannah River heavy water reactors, however, were another matter. In December of 1952, months before any heavy water reactor would go critical at Savannah River; Charles Wende, who would soon be head of the reactor work at SRL, discussed this issue. At that time, the only functioning predecessors to the large heavy water moderated production reactors being prepared at Savannah River, were the small research and test reactors at Argonne National Laboratory. These included: the Argonne exponential tank; the North American exponential tank; the CP-3 ["the world's first heavy water reactor"[32]]; and the Zero Power Reactor II, a small heavy water reactor commonly referred to as "ZPR-II" (the only other heavy water reactor in North America was the NRX Pile at Chalk River, Canada). Of these Argonne reactors, the most important to the development of the PDP was the ZPR-II.[33]

Even if the Savannah River reactors were based on the ZPR-II design, there were still great differences between the two. The ZPR-II, a relatively small tank that operated with twenty-five tons of heavy water, was less than one-quarter the volume of the PDP. ZPR-II could only determine neutron flux in the immediate vicinity of the fuel and target elements. It could not provide the big picture for a production reactor the size of those at Savannah River.[34]

In fact, the basic design of the R Reactor and the other production reactors at SRP, was based on measurements made in

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[31] E. I. Du Pont de Nemours and Company, *Savannah River Plant History, All Areas, August 1950 through June 1953*, 5-6.
[32] Jack M. Holl, *Argonne National Laboratory, 1946-96*, with assistance of Richard G. Hewlett and Ruth R. Harris; foreword by Alan Schriesheim (Chicago: University of Illinois Press, 1997), 51.
[33] Ibid., 149; Charles W. J. Wende, "Operation of PDP," Memorandum to L. Squires, E. I. Du Pont de Nemours and Company, Explosives Department, Wilmington, Delaware, December 9, 1952, 9.
[34] B. H. Mackey, "Reactor Safeguards — PDP," Letter to Curtis A. Nelson, Manager, U.S. Atomic Energy Commission, Savannah River Operations Office, Augusta, Georgia, February 26, 1953, 2; Wende, "Operation of PDP," 10.

the "exponential experiment" and in the ZPR-II at Argonne (with reactors, the term "exponential" refers to the rate of neutron flux in the reactor tank, and the conditions under which the neutrons fall off).

These measurements gave the designers the basic lattice information and the basic control data needed to operate the reactors. Even so, this information was obtained from tests in relatively small reactor tanks, and there was a need to run tests in a large-scale reactor tank before production got underway in R Area.[35]

Just having a large-size test reactor was found to make a difference in any tests pertinent to a large reactor. Testing element components in a small reactor was fine, but a small test reactor was not adequate for testing the behavior of neutrons in a larger setting. The loss of thermal neutrons was much less in a large reactor, simply because of the greater mass. One researcher compared the situation to a coal fire, where one lump of coal will hardly burn because it loses heat faster than can be generated through combustion. Only a pile of coal will burn efficiently.[36]

There were at least two effects that researchers wanted to test in a large reactor before any attempts were made to start up R Reactor. One was the "rooftop" effect of having so much heavy water moderator above the fuel and target elements in the tank. It was believed that this effect would improve power output in the larger reactors by at least ten percent. Such an effect was barely suggested in the ZPR-II because the reactor tank was not high enough.

Another effect was a "tilt" in the "flat zone" of the ZPR-II. The "flat zone" in a reactor is the central area that is exposed to the greatest concentration of thermal neutrons; the area surrounding the flat zone is often called the "buckled" zone, where the concentration of neutrons falls off, usually around the edge of the reactor tank. A tilt in the flat zone is any irregularity in the concentration of the thermal neutrons caused by an asymmetrical arrangement of the control rods. This appeared to have been a problem of "radial neutron

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[35] Wende, "Operation of PDP," 2.
[36] E. H. Lockwood, *Reactor Physics Primer*, General Electric, Hanford Atomic Products Operation, Richland, Washington, November 15, 1957, 76-7.

distribution"-- a problem that threatened to affect twenty percent of the reactor's output. Just noticeable in the smaller test reactors, it was expected that there would be greater tilt in the flat zone of a much larger reactor like R. Since researchers were not certain how this would be handled in R Reactor, they wanted to first test this effect in the PDP. A suitable resolution of this matter would allow power level increases within the larger reactors.[37]

Another issue that merited investigation was the addition of safety features for the larger reactors. In a study written by B. H. Mackey in 1953, it was determined that the ZPR-II and the PDP would have virtually the same potential hazards. The greatest of these, though unlikely, was the possibility of a slow runaway reaction that might continue until the moderator boiled away. As a result, it was decided to have sixty safety rod actuators for the PDP and a backup of shutdown rods. Once inserted, the shutdown rods would hold the reactor at a subcritical level. This would allow workers to enter the PDP room without having to pump out the moderator, as had to be done with the ZPR-II.[38]

There were a number of other safety features new to the PDP. There was the use of interlocks that would force operators to use the proper procedures when operating the reactor. Also, the PDP reactor tank could be brought to criticality only by withdrawing the control rods; the ZPR-II could be brought to a critical state by either raising the water level or pulling out the control rods. There would be at least twenty-one health monitors around the PDP and within the building; there were none for the ZPR-II. The PDP would also be below ground level for additional protection from any radiation. The PDP reactor room doors were gasketed, and there was a greater room volume around the reactor tank. Trip circuits were built into the system to shut down the heating and ventilation in case of accident. Last but not least, in the case of a slow runaway reaction, the PDP was set up so that steam in the quatrefoils would blow off the Q-foil caps. Moderator would then spill onto the floor, allowing the reactor to go subcritical.

In other more general ways, Building No. 777-M and its reactors had connections with Building No. 316 at Argonne. Many of the

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[37] Wende, "Operation of PDP," 2.
[38] Mackey, "Reactor Safeguards – PDP," 1-3.

general features of Building No. 777-M were modeled after Building No. 316. The location and function of both buildings within the overall complex were basically similar. Both buildings were designed around two heavy water moderated research reactors: Building No. 316 already had reactors ZPR-I and ZPR-II; Savannah River would soon have the much larger PDP, as well as the SP. Both buildings were situated close to other experimental reactor facilities: Building No. 316 was close to CP-5 at Argonne, while 777-M and its PDP would be close to the graphite reactor in Building No. 305-M. There would even be a comparable number of people around the reactors during the work week, which made its safety considerations similar.[39]

The PDP Tank

The design and construction of the PDP tank, and all the various items that were required to make the tank work, progressed at about the same time as the design and construction of the building itself. From the beginning, it was understood that the PDP would have to be a full-scale version of one of the heavy water moderated production reactors scheduled to go on line at Savannah River. It would have to operate at low power (up to around 100 watts). It would have to duplicate the chemical and physical properties of the production reactors–– similar in all things nuclear-- but not necessarily have the same mechanical design. It would also have to be versatile enough to allow for the study of advanced reactor designs and lattice arrangements.[40]

All of these aspects of the PDP played a role in the design of the tank itself, and the area around the tank. The PDP tank design was dictated by five general requirements: accurate production reactor mock-up (but only in chemical and physical aspects); safety; the preservation of the heavy water moderator; accessibility; and flexibility of use. Because the PDP did not have to ape the production reactors in all mechanical details, there was no need for a gas blanket or reactor coolant.

Alternatively, because operators would be working much closer to the PDP than would ever be allowed in the production reactors, it was decided to bump up the safety features. For the tank, this meant an array of shutdown rods that were not found in the

[39] Ibid., 2-4.
[40] Du Pont, *SRP Engineering and Design History*, Vol. IV, 21; Mackey, "Reactor Safeguards – PDP," 1; Dessauer et al., "Design Data Report," 11-12.

production reactors. These could be dropped into the tank quickly to stop reactivity, without having to change the control rods—most of which would be set by hand, and difficult to move quickly. To conserve heavy water, there had to be general protection from corrosion in the walls of the tank and the holding tanks and in the piping. The top of the reactor itself had to be sealed against dust and the introduction of light water vapor. There had to be a drying system to remove the residual heavy water whenever the tank was drained. For ease of access, there had to be space to work around the sides, the bottom, and certainly the top. For reactor flexibility, it was determined that a seven inch "pitch," would work best for the Savannah River reactors. "Pitch" is the distance between rods in the reactor tank, measured from center to center.[41]

One of the first firms to do work on the PDP tank design, aside from Du Pont, was the American Machine and Foundry Company (AM&F). This firm specialized in making industrial machines for other companies, and had been responsible for making what was then the world's largest cigar and cigarette manufacturing equipment. By the late 1940s, the firm had branched into the realm of military equipment. In November 1950, AM&F was contacted about doing much of the machine work for Savannah River, and the company set up a Special Projects Laboratory in Brooklyn, New York, for "Project XYZ," the firm's designation for the Savannah River work. This work began in November of 1950, when AM&F received a letter of intent from Du Pont that later became a subcontract. This subcontract was modified for the first time on August 15, 1952, and went through eight modifications by October of 1953. By the time AM&F's main work on Project 8980 Project was completed in 1954, the firm had done much of the work for the equipment in the 100, 200, 300, and 700 areas of Savannah River Plant.[42]

[41] Du Pont, *SRP Engineering and Design History*, Vol. IV, 147-9; Dessauer et al., "Design Data Report," 14; Norm Baumann, personal communication, October 19, 1999.

[42] American Machine and Foundry Company, *Savannah River Plant Engineering and Design History, Volume I of IV*, American Machine and Foundry Company, New York, E. I. Du Pont de Nemours and Company, Engineering Department, Wilmington, Delaware, Prime Contractor for United States Atomic Energy Commission, U.S. Contract No. AT(07-2)-1, Du Pont Project 8980, Subcontract No. AXC-8-1/2, February 28, 1954, 6; American Machine and Foundry Company, *Savannah River Plant Engineering and Design History, Volume III of IV*, American Machine and Foundry Company, New York, NY, E. I. Du Pont de Nemours and Company, Engineering Department, Wilmington, Delaware, Prime Contractor

The AM&F contract for design work in the 100 Area was enlarged to include work on the PDP in September 1951. At that time, AM&F was asked to design a low power reactor with a flexible lattice arrangement. This reactor would be a duplicate of the production reactors in most respects, and would use as many of the regular 100 Area vertical elements as possible. Many of the general arrangement drawings that were to be the basis for these plans were provided by VWF&S.[43]

In the official history of the AM&F work done at Savannah River, AM&F outlined the steps that were taken to work up the plans for the PDP. Designs from the Hanford plant were examined for possible use at SRP, but it was quickly found that most of those designs were too old to be useful. Even so, AM&F began working up plans for the test reactor tank in late 1951 and early 1952. As early as November of 1951, AM&F had prepared a proposed design for the tank that included expandable beams and deck plates that would allow changes in the lattice pitch from 7" to 10" maximum. The firm also worked on the designs for the shutdown rods and the safety drives.[44]

Despite this level of effort, it appears that Du Pont was not satisfied with the results. After AM&F worked up various design possibilities for the operation of the PDP, Du Pont found them too complicated and inflexible. Du Pont sent a formal letter to AM&F, dated March 19, 1952, canceling much of their work on the PDP. In the months that followed, AM&F worked on various design aspects of the controls, and the vertical components that went into the reactor. These included the Q-foils, the S-foils, the control safety rods and the rod drives, even the assembly and disassembly machines. They did not, however, include work on the tank.[45]

For additional design work on the tank, Du Pont decided to scrap the AM&F plans and return to Du Pont's original plans, dated before September 1951. The final plans for the PDP tank design

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for United States Atomic Energy Commission, U.S. Contract No. AT(07-2)-1, Du Pont Project 8980, Subcontract No. AXC-8-1/2, February 28, 1954, 591.

[43] Du Pont, *SRP Engineering and Design History*, Vol. IV, 149-150; American Machine and Foundry, *SRP Engineering and Design History*, Vol. I, 1043-4.

[44] American Machine and Foundry, *SRP Engineering and Design History*, Vol. I, 24, 1042, 1045-1056.

[45] Ibid., 1044; Du Pont, *SRP Engineering and Design History*, Vol. IV, 150.

were done by VWF&S, in cooperation with Du Pont's Design Division. These plans included the tank design, the lattice support arrangement, the materials handling and storage equipment, and the control rod drive. They maximized lattice flexibility and the flexibility of reactor control.[46]

It is clear that these PDP plans were all worked up in early 1952. They called for a Type 304 stainless steel cylindrical tank that had an inside diameter of 16'-2-3/4" and a height of 16'-0". Usable liquid height inside the tank would be 15'-3". The tank walls were to be 1/2" thick; the base, 1" thick. The tank would be elevated above the moderator storage tanks, so that it could drain by gravity. There would also be a tank cover to prevent contamination of the heavy water moderator, and to allow several people to work on the tank top at one time. The tank could accommodate 606 fuel tubes in 151 quatrefoils, sixty-one septifoils, sixty safety rods, and sixty shutdown rods. In addition, allowance was made for an 8" porthole on the side of the tank, at about 7'-7" above the inside tank bottom. This porthole, referred to as a "bull's-eye sight glass," was installed to aid the calibration of level instruments inside the tank. It could also be opened to insert a tube to check neutron spectrum or to obtain a neutron beam for special experiments. The PDP also had a resin bed to keep ion concentrations below the level of corrosion. Allowances were also made for "reflector cans," which would occupy the space above the highest fuel slugs. These cans would be filled with heavy water and would serve to mimic the additional heavy water features of the regular production reactors that would not be present in the PDP.[47]

The firm that actually fabricated the PDP tank was New York Shipbuilding Company, based in Camden, New Jersey. This firm was already under contract to Du Pont to produce the production reactor tanks, when they were also asked to produce what New York Shipbuilding called the "Physics Lab Tank."

New York Shipbuilding became involved in Project 8980 in early 1951, when they were contracted to construct the first prototype of the Savannah River production reactor tank, to be followed by the production reactor tanks themselves. This work, identified

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[46] Du Pont, *SRP Engineering and Design History*, Vol. IV, 149-150.
[47] Du Pont, *SRP Engineering and Design History*, Vol. IV, 150-151; Dessauer et al., "Design Data Report," 13, 15-16, 27.

as the "NYX Project," was conducted in great secrecy from 1951 through 1954.[48]

The prototype tank, which became known as the "NYX" Tank, was a cylindrical tank 25'-0" high, with a diameter of 16'-0" in the mid-section, but was flared at the top and bottom, where it measured 19'-0" diameter. There were four main assemblies with this tank: the main tank itself; the plenum chamber; the top tube sheet assembly; and the bottom tube sheet assembly. The plenum and the top and bottom sheet assemblies all had synchronized holes that would allow for the passage of the reactor elements into the tank. AM&F made many of the components that went with the NYX tank. The fabrication of the NYX tank began in September of 1951 and was completed in May of 1952. Due to the pressing schedule imposed on Savannah River, the R Reactor tank was begun as early as October of 1951.

Ironically, the PDP tank, an integral part of an experimental reactor that had to do its work before the R start-up, was actually constructed after work had already begun on many of the production reactor tanks. The first mention of any PDP tank work is dated to January 11, 1952, when Du Pont modified the New York Shipbuilding contract to allow for the construction of the "Physics Laboratory Tank and the Grid Beam Assembly," to be done for a fixed fee of $7,500 and an estimated cost of $75,000. The notification to proceed with this tank was issued in June 1952.[49]

As a result, the tank itself was constructed at New York Shipbuilding in the latter part of 1952. The tank fabricated was 16'-0-1/2" high, with an interior diameter of 16'-2-3/4". The tank bottom had a "flanged only head" that was made by Lukens Steel Company, based in Coatesville, Pennsylvania. The upper part of the tank had four chambers spaced around the rim that extended 3'-4" down the side, with flanged connections.

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[48] New York Shipbuilding Corporation, *Savannah River Plant, Fabrication and Testing History, Prototype and Production Units*, New York Shipbuilding Corporation, subcontractor for Engineering Department, E. I. Du Pont de Nemours and Company, Wilmington, Delaware, Prime Contractor for United States Atomic Energy Commission, U.S. Contract No. AT(07-2)-1, Du Pont Project No. 8980, Subcontract No. AXC-167-1/2, September 1954, 11-13, 28-29; New York Shipbuilding Corporation, *History, Project 8980 – NYX*, Du Pont Construction Division, New York Shipbuilding Corporation, Camden, New Jersey, AXC 1671/2 – Du Pont Contract No. CT-4143.

[49] New York Shipbuilding, *SRP Fabrication and Testing*, 17, 20, 69-70, 83, 287-289.

The tank support framework was made with carbon steel I-beams, lined with stainless steel in the vicinity of the tank. The diaphragm plate directly above the tank was a square stainless steel construction that measured 17'-8-1/4" to a side, and was 0-1/4" thick. The circular opening in the middle of the plate measured 16'-5-1/2" diameter. Above the diaphragm was the grid beam assembly, consisting of thirty-one grid beams that were designed to hold the support plates and the aluminum cover plates. There were twenty different sizes of cover plates, to accommodate the different possible arrangement of the vertical elements that would go into the reactor tank. The tank and the grid beam assembly were all shipped to Savannah River on January 15, 1953 with the third barge shipment to the plant.[50]

There is some question about the nature of the original PDP tank top. It is clear from sources dated to 1952, that there was some sort of tank top planned for the PDP to close the reactor. Dessauer et al. describe a tank cover that would prevent contamination of the heavy water, and support the weight of several people simultaneously.[51] New York Shipbuilding clearly made something like this, and it sounds much like the tank top that was present in 777-M right up until 2005, when it was dismantled during the building demolition process. Alternatively, scientists associated with 777-M's operational years, Norm Baumann and Tom Gorrell, have maintained that the tank top present in later years was not in place in 1953, when the tank was first used.

During the construction of the tank, much work was done on the auxiliary equipment that was required in the operation of the PDP. One important aspect of this equipment was the heavy water system, which included storage tanks, piping, and water level controls. Initially, the system was designed for a total of 100 tons of heavy water, but this was later changed to 110. Water levels in the tank could be adjusted from 3'-0" to 15'-3" inside the tank. The tank could be filled within thirty minutes, and drained in ten. Water temperature could range from room temperature to 125 degrees Fahrenheit. There was also a heavy water drying system set up in the tank and the piping to capture

[50] Ibid., 237-8.
[51] Dessauer et al., "Design Data Report," 15-16.

heavy water moisture as possible when the tank was emptied.[52] It appears, however, that this drying system was rarely used.[53]

Just as important as the tank were the vertical elements that entered the tank. These provided the raw materials for any reactivity to take place. Since the PDP operated at very low power, there was no need for a large neutron source. There were only two polonium-beryllium neutron sources, which would normally be placed near the center of the tank. Each source emitted 2 x 10 to the seventh power number of neutrons per second. Operated by remote control, the source rods were either in the PDP when in use, or they were stored in a cylindrical can 2'-0" tall and 1'-0" in diameter, filled with a boron carbide-paraffin mix. The source rods were designed to fit into any of the safety rod thimbles.[54]

There were sixty safety rods for the PDP, and the length of the absorber element on each was 14'-0". There were another sixty shutdown rods, basically identical to the safety rods, which provided a greater degree of security in the operation of the PDP. These shutdown rods were divided into four "gangs" or groups, each of which operated as a unit.

Of greater concern for the operation of the tank were the 427 control rods, most of which were designed by AM&F. Most of the control rods (357) were designed to be set manually and then clamped in place. The remaining seventy could be operated remotely and moved individually or in gang fashion. As in the production reactors, the control rods were grouped into septifoils, each one of which contained seven control rods. As a result, there were a total of sixty-one control rod assemblies: fifty-one set manually and ten operated remotely.[55]

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[52] Mackey, "Reactor Safeguards – PDP," 6; Du Pont, *SRP Engineering and Design History*, Vol. IV, 153.
[53] Tom Gorrell, personal communication, November 14, 2006.
[54] Dessauer et al., "Design Data Report," 29.
[55] Ibid., 17; Mackey, "Reactor Safeguards – PDP," 6-7; Du Pont, *SRP Engineering and Design History*, Vol. IV,152; American Machine and Foundry Company, *Savannah River Plant Engineering and Design History, Volume IV of IV*, American Machine and Foundry Company, New York, E. I. Du Pont de Nemours and Company, Engineering Department, Wilmington, Delaware, Prime Contractor for United States Atomic Energy Commission, U.S. Contract No. AT(07-2)-1, Du Pont Project 8980, Subcontract No. AXC-8-1/2, February 28, 1954.

In addition to the control rods, there were the reactor fuel assemblies. There were a total of 606 fuel assemblies to be placed in the reactor. These 606 fuel assemblies were quatrefoils, also known as Q-foils. As the name implies, there were four fuel tubes in each Q-foil. For a normal PDP loading, there would be twenty slugs per tube, or eighty per assembly, for a total of 48,480 slugs per loading. The average weight of each slug was 4.31 pounds. The total weight of the uranium was 104.5 tons; the weight of the uranium-235 within this total was 1,484 pounds.[56]

Even though the PDP was basically the same as the production reactors, the differences in the operation of the tanks required some differences in the vertical elements. The Q-foils in the PDP were slightly longer and the bottoms of the elements were also partially covered, since there was no need for coolant flow. To compensate for the reduced level of heavy water above the tank, aluminum cans filled with heavy water occupied the spaces above the highest slugs in each fuel tube of each quatrefoil.[57] Because there was very little power generated in the PDP, it was possible to use bare uranium slugs, rather than the aluminum-clad slugs that had to be used in the production reactors. To replicate the situation found in the production reactors, aluminum "spacers" were used between the slugs to mimic the spacing that would have been formed by the end-of-slug cladding in a production reactor.[58]

Naturally, many of these vertical elements had to be controlled mechanically, and this fell under the category of the PDP element motor control work. The Du Pont Design Division did most of this labor, with some specific tasks handled by VWF&S. Together, they created a "rack structure with fused caps for insertion into a three-phase 110 volt bus receptacle."

The control rod cables, and other cables, went into a sheave rack at the +27'-0" level over the tank. This meant cables for the seventy remote-operated control rods. At the operator end, steel tapes graduated into centimeters were attached to the cables, so that operators would have a direct reading of the control rod positions. The other cables for safety rods and shutdown rods, were also were also put over pulleys on the

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[56] Mackey, "Reactor Safeguards – PDP," 6.
[57] Du Pont, *SRP Engineering and Design History*, Vol. IV, 154.
[58] Ibid.; Dessauer et al., "Design Data Report," 11.

sheave rack and on motor-driven drums. All of this was different from, and cheaper than, the rack and pinion system employed in the 100 areas.[59]

One stand-alone piece of equipment that was critical to the loading and unloading of the vertical elements, was what was referred to as the "tilting table" or "tipping table." Most of the vertical elements, especially the fuel tubes, were structurally weak in any position but vertical. Even so, most could not be assembled except in a horizontal position. The horizontal tilting table was long enough to hold any of the vertical elements, and came equipped with "V"-shaped slots to keep the element from rolling off. The table could then pivot to a vertical position and elevate as needed to secure the element to the appropriate cable or storage area. This process was called "verticalization."

The table, developed by AM&F and first used at New York Shipbuilding in late 1951, was essential for the loading of slugs, spacers, and cans. It was a long, narrow table that measured 25′-0″ x 7′-0″. It could rise to a height of 25′-0″. The original design called for the use of a friction clutch in the drive mechanism; this was later changed to a solid coupling. Work also had to be done on the latching mechanism that held the table in position. All of these issues were worked out before the installation of the first tipping table in 777-M. This was fortunate, since the success of the tipping table was critical to the successful loading of the PDP.[60]

A number of other instruments surrounded the PDP and were important for its operation and control. Many of these were monitoring instruments, such as the ten boron-coated ion chambers and the twenty-one health monitors. Other important pieces of equipment inside the PDP tank were the vertical and horizontal traveling monitors that measured neutron flux. There

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[59] Du Pont, *SRP Engineering and Design History*, Vol. IV, 152-155.
[60] Ibid., 154-5; New York Shipbuilding, *SRP Fabrication and Testing*, 71; American Machine and Foundry, *Savannah River Plant Engineering and Design History, Volume II of IV*, American Machine and Foundry Company, New York. E. I. Du Pont de Nemours and Company, Engineering Department, Wilmington, Delaware, Prime Contractor for United States Atomic Energy Commission, U.S. Contract No. AT(07-2)-1, Du Pont Project 8980, Subcontract No. AXC-8-1/2, February 28, 1954, 530-535; Tom Gorrell, personal communication, May 19, 2006.

were other instruments that recorded and controlled the liquid level in the tank, as well as temperature and radiation levels.[61]

The SP and SE Tanks

The other initial reactor complex inside Building No. 777-M consisted of the Standard Pile (SP) and the Subcritical Experimental facility (SE). Both of these facilities were located in the "Standard Room," in the northwest corner of the building. The SP was planned for the building from the beginning, but the SE was added after building construction was already underway. Even so, it is pretty clear that allowances had always been made for something like the SE to be positioned over the SP. This was the arrangement that was eventually worked out by the time the building was constructed, with the SP resting on the minus 15'-3" level, the SE tank directly above it, with the top of the SE tank located at the 0'-0" level.[62]

The three basic functions of the SP were: 1) to provide "a flux of neutrons for the calibration of foils and instruments used with the PDP"; 2) to determine neutron cross sections and/or danger coefficients of samples; this included cross section determinations involving neutron beams; also included in this work were exponential experiments, where the SP provided neutrons to the SE; and 3) to serve as a primary standard for calibrating health monitoring instruments and for maintaining standards of nuclear quality control.[63]

The basic design for the SP was taken from General Electric's Thermal Test Reactor at the Knolls Atomic Power Laboratory in Schenectady, New York. The major difference between the two was in the orientation of the reactors. The Thermal Test Reactor had a vertical orientation, with elements going in and out of the top. The SP was oriented horizontally. As a result, elements entered the reactor from the side, and the neutron beam from the reactor also left from the side. Since the elements were horizontal, the resulting horizontal beam would be more symmetrical. It also left the top of the SP free for future additions, such as the SE.[64]

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[61] Mackey, "Reactor Safeguards — PDP," 8; Voorhees Walker Foley and Smith, *SRP Engineering and Design History*, Vol. I, 100-2.
[62] Du Pont, *SRP Engineering and Design History*, Vol. IV, 159.
[63] Ibid., 130; 155-6; Dessauer et al., "Design Data Report," 42.
[64] Dessauer et al., "Design Data Report," 43-44.

The horizontal neutron beam generated by the SP went through a 4'-0" x 4'-0" opening in the 6'-thick shielding wall, directly into the Nuclear Physics Laboratory and the Beam Room. This allowed for a full, unimpeded expanse of 120 linear feet for any neutron beam testing. When not in use, the opening in the wall was filled with graphite blocks.[65]

Unlike the PDP, there was no cutting edge reactor design or technology involved in the SP. The reactor itself was graphite-moderated, as were most reactors at that time. The General Engineering Laboratory of General Electric, the manufacturer of the Thermal Test Reactor, also made the SP. There were of course some differences, based on the differences in the orientation of the reactor elements. The core of the SP was a straight-through passage for samples, and the SP control rods operated with a reset-type switch, rather than the older manual on-off button. The reactor fuel container was created from two aluminum cylinders, one with 10-1/2" interior diameter, and the other 18" interior diameter. The cylinders were connected by two aluminum rings. The inside of this device contained a rotary rack for the fuel rods, which consisted of fourteen 3"-diameter fuel loading rods designed to hold uranium-235 fuel disks, covered by aluminum alloy. A light-weight paraffin oil served as the coolant. In the center of the reactor was a 4-1/2" aluminum tube, which was the passage for inserting loadings in the 4"-diameter graphite rod. All of this was situated in the middle of a five-foot cube of graphite, which comprised the outer edge of the reactor itself. In addition to source and fuel rods, the three cadmium control rods and the four cadmium safety rods, all 18" in length, entered the reactor from the side. General Electric fabricated the SP in 1952, and sent the reactor to Du Pont and the Savannah River Plant in early 1953, together with a draft of the pertinent test procedures.[66]

The SP was designed so that an exponential tank could fit on top. This exponential tank was identified by a number of

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[65] Ibid.; Du Pont, *SRP Engineering and Design History*, Vol. IV, 157.
[66] Du Pont, *SRP Engineering and Design History*, Vol. IV, 156-157; "Standard Pile Test Procedure and Results, Draft: GL-67000," General Electric, General Electric Laboratory, Schenectady, New York (Sent to G. Dessauer, Atomic Energy Division, Explosives Department, E. I. Du Pont de Nemours and Company, Wilmington, Delaware, from J. L. Matrone, General Engineering Laboratory, Schnectady, New York, January 15, 1953).

different acronyms. The most common designation now is the SE, or "sub-critical experiment" or "sub-critical experimental facility." In the early days, the SE was also known as the EXP, or "exponential pile." It was also known as the "exponential tank."[67]

The SE or exponential tank was designed for small-scale tests of fuel and lattice arrangements, as well as chemical and physical reactions. The SE allowed the study of various types and sizes of fuel elements under reactor conditions, without having to tie up the much larger PDP for that purpose. It was designed with a flexible lattice arrangement so that any new type or shape of fuel element could be tested in the tank under reactor conditions. If it was found to be suitable in the SE, then the element or lattice arrangement could graduate to the PDP, if necessary. The thermal neutrons for the tests would be supplied externally, from the SP. These neutrons could be projected from the SP through the graphite pedestal that separated the SP from the SE. The neutrons would then activate samples in the SE tank.[68]

Design work on the exponential tank began on January 6, 1953, relatively late in the overall history of Building No. 777-M construction. All details and pertinent drawings were completed in May of 1953, when the rest of the building was almost completed.[69] The SE design was based on that of the exponential tank used at Argonne National Laboratory; the interior diameter of the tank was the same, but the SE tank was higher and with a different tube arrangement. The design work itself was done by VWF&S, with oversight by Du Pont. The elements that were used in the tank were adapted from the PDP, but were made smaller for this smaller tank. The tank itself was fabricated by a "commercial metals fabricator."[70]

As constructed, the SE was a cylindrical tank with an interior diameter of 5'-0" and an overall height of 8'-0", including tube supports and the tank cover. The tank itself was fashioned from 0-1/2" thick aluminum. This was topped with a 0-1/16" thick

[67] Du Pont, *SRP Engineering and Design History*, Vol. IV, 158; Voorhees Walker Foley and Smith, *SRP Engineering and Design History, Vol. I*, 100.
[68] Du Pont, *SRP Engineering and Design History*, Vol. IV, 21, 158-9.
[69] Voorhees Walker Foley and Smith, *SRP Engineering and Design History, Vol. I*, 175; *Vol. II*, 158.
[70] Du Pont, *SRP Engineering and Design History*, Vol. IV, 158.

cadmium covering held in place by stainless steel banding. Like the PDP, and unlike the SP, the SE used heavy water as a moderator. The maximum water depth in the tank was 6'-1". The piping system was set up for maximum flexibility, just like the PDP. As was the case with all heavy water moderated reactors, the fuel and control rod elements entered the tank from the top. As initially planned, there were to be no control rods in the exponential tank, but these were added soon after. The tank had a rotating cover that allowed for maximum flexibility, and the components that entered the tank were like those of the PDP, except shorter. All control rods were set manually.

The SE or exponential tank was placed over the SP, with a 16" graphite pedestal between the bottom of the SE tank and the top of the graphite cube that surrounded the SP. The top of the SE tank was situated at 0'-0" level of the SP room (the base of the SP reactor rested on level minus 15'-3"). In the SP room, the 0'-0" level around the SE top had a floor of steel grating. The 1,000-gallon storage tank for the SE heavy water moderator was installed at Level --15'-3".[71]

The First Era of Building No. 777-M, Summer-Fall of 1953

Perhaps the most important period in the whole history of 777-M, were the first few months of operation, during the summer and fall of 1953, before R Reactor went critical.[72] This crucial period was recognized months before the PDP went critical.[73] Not only was this the first instance of a large-scale heavy water moderated reactor going critical within the AEC complex, but the PDP had an important role to play in the successful start-up of the R Reactor, the first of the heavy water moderated production reactors at Savannah River. Du Pont had promised the AEC that it would have the first production reactor on line before the end of 1953, and this was a benchmark that had to be made.[74] As Charlie Wende put it in December of 1952, the operation of the PDP "several months in advance of the R Pile startup, will help us to achieve and sustain full-power operation of the R-Pile more quickly and certainly." Without the PDP, it was accepted that it might take a year to complete the first cycle of the R

[71] Du Pont, *SRP Engineering and Design History*, Vol. IV, 158-160.
[72] Tom Gorrell, personal communication, January 30, 2006.
[73] Wende, "Operation of PDP," 1
[74] Tom Gorrell, personal communication, January 30, 2006.

Reactor. With the information that could be provided by the PDP, this time period could be cut by months. "In view of the large potential gains, and the small risk to the heavy water [moderator], it is recommended that the PDP be started up as far in advance of the R-Pile as possible."[75]

The Importance of the PDP

The first detailed examination of the importance of the PDP was a document compiled by Charlie Wende in December of 1952, several months before the PDP was scheduled to go critical for the first time. Wende described the nature of the work that would be done in 1953 and possibly in the years to follow.

As has been said before, the primary significance of the PDP was its size. It was virtually identical to that of R reactor, and any physics measurements that might be made in the PDP would be directly applicable to R reactor or any of the other production reactors. Neutron flux measurements would be similar, even though the power levels in the two reactors would be very different. Normal flux operation for the core of the PDP would be something like ten to the sixth power neutrons per squared centimeter per second, which would rate at around twenty-five watts of power. The upper limits would be around ten to the eighth power, or two to three kilowatts.[76] Alternatively, R reactor was initially rated at 378 megawatts[77] and in later years would be pushed much higher than that.

The PDP was designed to measure neutron flux in a way that R Reactor was not. According to Wende, use of the PDP would determine detailed knowledge of neutron distribution and "reactivity effects" in a "cold, clean environment." It would also provide a good standard for neutron measurements, especially when other factors would be at play in the production reactors, such as heat and poisoning. In the PDP, this standard would be determined by traveling monitors inside the tank and by special fuel assemblies that contained foil or pin traverses—equipment that would be too delicate to survive in a production reactor. The PDP was designed to extend the sort of nuclear information now obtainable only in the much smaller ZPR-II reactor. This information would provide a more realistic

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[75] Wende, "Operation of PDP," 1.
[76] Mackey, "Reactor Safeguards — PDP," 2-3.
[77] Wende, "Operation of PDP," 14.

understanding of the neutron fluxes that could be expected in a production reactor. Without the PDP, all Savannah River Reactor Technical standards for the production reactors would be based on computations that would not be particularly accurate and would therefore require large margins of error for safety reasons. Operation of the PDP would lead to a more realistic knowledge of a large reactor, and would provide practice in the operation of such a reactor. Addressing the physics questions in the PDP would allow the production reactors to operate at higher power more quickly.[78]

The two basic issues to be determined by the PDP were how neutron distribution in the reactor would limit or effect production reactor power, and a determination of the outer margins of operational safety. All such readings in the PDP would be done with an array of foils, pins, wires, chambers, and traveling monitors. All of these instruments would be placed in different locations throughout the reactor, so that operators could get a clear view of the neutron range in various parts of the reactor. With such means, it was expected that the PDP would answer a number of specific questions within an estimated seventy-five work shifts, or approximately three months of operation.[79] Those issues are discussed below.

There were three specific issues that the PDP would address in 1953, and these were detailed in Wende's report.[80] They are mentioned here and are listed below with more details: 1) the establishment of a specific loading pattern for the production reactors; 2) establishment of the limits of safe operation of the reactors; and 3) the establishment of methods of initial operation.

1. Establishment of a specific loading pattern for the production reactors.

    a. What pattern should be used in the arrangement of the ganged full rods of the control system?
    b. Will there be "hot spots" in the intermediate and buckled zones of the reactor, and will this affect power increase? If there are hot spots, how they be compensated for, using control rods and the zoning of elements?

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[78] Ibid., 2-3, 14.
[79] Ibid., 3, 6-7.
[80] Ibid., 3-5.

c. In cycles where plutonium is produced, is it worth loading fuel in some of the control rods in the intermediate zone?

2. Establishment of the limits of safe operation.

a. How effective are the safety rods? How many rods could be pulled out of the reactor, and in what patterns, and still run the reactor safely?
b. Is safety control also possible if the level of heavy water is reduced?
c. How many control clusters can be out of the reactor at any given time?

3. Establishment of the methods of initial operation for the production reactors

a. What rod configuration is needed to reach criticality?
b. What rod configuration is needed to establish a "flat zone" at zero power?
c. "What is our full-rod calibration in the flat and intermediate zones, for several half-rod settings in the neighborhood of the optimum rooftop?"
d. How much "trim" is required to compensate for local poison?
e. How to manage half-rods with and without rooftop monitors? How important are the half-rods?
f. Establish a program of rod withdrawal as the reactors approach criticality.

In order to understand the importance of the issues mentioned above, there has to be an understanding of the terms, some of which are not only specific to the nuclear community, but even specific to the nuclear community at Savannah River.

The very essence of the nuclear reactors at Savannah River is the presence of thermal neutrons. They are emitted from the reactor source material (usually the fuel rods), are slowed down by the moderator, and then are accepted into a target material to make a fissionable isotope. Even the "high flux reactor activities" at Savannah River were based on the use of relatively slow thermal neutrons.[81]

[81] Chuck Jewell, personal communication, May 22, 2006.

The thermal neutron flux shapes within a reactor tank determine the areas of greatest efficiency, as well as the less productive but inevitable areas of neutron fall-off. The PDP was specifically designed to study these flux shapes. The most efficient and uniform was known as the "flat shape" or "flat zone," located in the center of the reactor tank. The secret to good reactor operation was to increase the size of the flat zone at the expense of the intermediate and "buckled" zones. The buckled zone, located at the edge of the reactor, was marked by a rapid fall-off of thermal neutrons. Reactor operation was most efficient when this buckled zone could be kept as narrow as possible, yet still do the job of preventing neutrons from escaping the reactor tank. The constant concern with reducing the buckled zone eventually led to the creation of "blanket loadings," which were the rather inert last ring of reactor elements, usually lithium assemblies, designed both to capture neutrons at the edge of the reactor tank and to reduce the heat load on the tank wall.

The term "buckling" meant something different from "buckled." An expression that appears to have been used more at Savannah River than at any other AEC nuclear facility, "buckling" simply referred to the reactivity of a particular lattice arrangement. The greater the reactivity, the greater the "buckling."

Whereas flat zone and buckled zone generally referred to the horizontal flux shape of the reactor, analysis of the vertical flux shape, or the top-to-bottom distribution of neutron flux, involved "rooftopping." The optimal "rooftop ratio" was one where the axial measurements were the same both one-quarter into the reactor tank, and again three-quarters of the way into the tank, with the greatest distribution of neutrons occurring between those reference points.

Neutron distribution, whether horizontal or vertical, was regulated by control rods. To fine tune the reactivity within the tank, it was understood from the beginning that this would require both full rods and what were called partial rods. Any small change in the position of these rods was called "trim" or "trimming." This entailed moving individual control rods, done at a "trim panel" within the control room.[82]

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[82] Tom Gorrell, personal communication, January 30, June 13, July 25, 2006; Norm Baumann, personal communication, October 7, 1998.

Even though the three issues listed above were the main ones that concerned operators in 777-M during middle and latter part of 1953, there were other issues that were still important, and were scheduled to be addressed after the first few critical months. These included general safety issues; the effect of temperature to the system; and a number of different possible improvements to the general operation of the production reactors. All of the same questions and issues listed above also needed to be addressed for other types of fuel elements not yet tried at Savannah River, but already contemplated, such as enriched uranium, depleted uranium, and thorium.[83]

Final Equipment for PDP and Start-Up, 1953

In order to achieve Wende's goals, however, it was essential to finish outfitting the PDP in the first half of 1953. An order was placed for three polonium-beryllium neutron source rods in January of 1953, with the arrival date scheduled for April of that year. Two of these rods were for the PDP, with the third set aside for instrument checks. Beginning with this order and continuing for almost three decades, one or two new neutron sources would be required every year in Building No. 777-M.[84]

To read the neutrons within the PDP, it was necessary to have a traveling neutron monitor suspended inside the reactor tank. The one used at 777-M was designed by Argonne National Laboratory. It could move horizontally within the tank and provide readings to the control room.[85] Using an ion probe, this instrument provided the basic reading of the neutron flux within the tank. In the early 1950s, this traveling monitor was simply the best way to measure neutron flux that was then available. Improvement to this device was a constant theme in the refinement of the operation of the PDP.[86]

The first testing of the PDP instruments was done in May and June of 1953. During that period, the early flaws of the

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[83] Wende, "Operation of PDP," 4-6.
[84] G. Dessauer, "Neutron Sources for Building 777-M, Savannah River Laboratories," Letter to Joel V. Levy, Wilmington Area Office, United States Atomic Energy Commission, Wilmington, Delaware, January 7, 1953.
[85] Du Pont, *SRP Engineering and Design History*, Vol. IV, 152.
[86] Peter Gray, personal communication, 17 May 2006; Wahl, "History, Savannah River Laboratory," 16.

process were detected and corrected.[87] Also during this period, the first tests were done with de-ionized water rather than heavy water. For some tests, de-ionized water would serve as a substitute for heavy water, which was very expensive, costing hundreds of dollars per pound.[88]

Among the instruments that had to be installed in and around the PDP were high-level flux monitors, period meters, and trip points. The four high-level flux monitors around the PDP were chambers with electrodes with high voltage, and a small amount of uranium-235 inside the chamber. Neutrons from the PDP would strike the instrument, and thus give an indication of the power level inside the reactor. Someone had to check this monitor continuously during PDP operation.

Period meters were designed to check the rate of change in neutron levels. In this case, a "period" represented the number of seconds it takes the flux to increase by a factor of "e." As with the high-level flux monitor, someone had to monitor this device during the operation of the PDP. The trip points would activate when the period got too low; they could initiate a scram that would shut down the reactor. There were other devices as well, such as those to measure the control rod positions, and indicate the level of heavy water in the tank.[89]

All of these things were installed and made operational throughout the summer of 1953, during a period of frantic activity in 777-M. The PDP itself began operations in September of that year[90] and the PDP first went critical in October. By all accounts, the tests that followed were based on the lines of enquiry established by Wende in December of 1952. According to informants who worked in Building No. 777-M during that first year of operation, the main issues outlined by Wende were in fact adequately addressed in the months before the start-up of R Reactor. There is also little doubt that this PDP work made it both safer and more efficient to start up R Reactor in late December of 1953.

During this period, when the PDP was running its initial tests, the reactor tank would go critical in the following manner.

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87 Wahl, "History, Savannah River Laboratory," 17.
88 Tom Gorrell, personal communication, January 30, 2006.
89 Ibid.
90 Dunklee, *Heavy Water System*, 5.

After all the vertical elements were in place, then the heavy water would be pumped up. After that, the safety rods would be pulled out, followed by the control rods. This would lead to rapid neutron multiplication, which would continue until a "period" was reached. When too many neutrons were created and the reactor started generating low power, some of the control rods were reinserted to bring the tank back under control. The PDP would operate in this manner with low power, and was not considered a threat to safety. Even so, the doors to the reactor room were always shut whenever the PDP was in operation.[91]

The SP and SE in 1953

During the critical year of 1953, it is clear that the PDP stole the show in Building No. 777-M. The SP and SE complex also started up during this same period. In 1953 at least, most workers in 777-M considered the SE the most important of the two later test reactors. Here, researchers could test the reactivity of small lattices. This work started out with slugs made of natural uranium, but later progressed to enriched uranium and other materials as well. The thirty positions in the SE could be loaded in one hour, if needed, and the tank filled with heavy water in a process called "pump-up." Although the SE was always sub-critical during operation, it was good for testing lattices and neutron flux before loading the entire thing into the PDP. Although less flashy, the SP provided the SE with neutrons and was an essential part of the operation.[92]

As might be expected, the SP went critical at least two months before the PDP. The first critical loading took place in July-August of 1953, and was achieved with over two thousand grams of uranium-235 placed into over 400 fuel disks.[93]

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[91] Tom Gorrell, personal communication, January 30, 2006.
[92] Ibid.; SP-SE Log (with entries from January 15, 1971 to April 30, 1979, when Building 777-M went on standby).
[93] SP Approach to Critical, Notebook with SP Results, from August 1, 1953 to August 21, 1953.

Workers and Security

Naturally, the PDP and the SP-SE operations could hardly take place without the presence of a dedicated work force to manage and interpret the results. There was an influx of Physics Programs personnel to Savannah River in the spring of 1953, as the plant began to start operations. Many of these newcomers were assigned to 777-M. Their first tasks were to oversee the final stages of building construction, check all equipment, write the process and safety procedures, and plan the first experiments. Among the experiments mentioned by name were neutron flux rooftopping; neutron spectrum; LM criticality; PDP criticality; and the problems associated with heat generation in the thermal shields. Much of this work went on in Building No. 777-M itself, but many aspects were studied in the main laboratory facility in A Area. This included four specialists in the Mathematical Physics group who worked with the IBM Card Program Calculator. This was recounted by Milton Wahl, the first director of the SRL and author of the laboratory's first history.[94]

If Milton Wahl was the overall "captain" of the SRL, Charlie Wende was the "executive officer" in charge of day-to-day operations throughout the Laboratory.[95] Wende prepared the report that outlined the first scope of work for Building No. 777-M and the PDP. Even Wende, though, had his office in the main building of the SRL. Among those who were assigned to 777-M and were present at the beginning of operations was Tom Gorrell. Gorrell first came to Savannah River in the summer of 1953, and worked at the plant his entire career. He was assigned to 777-M almost immediately to work in reactor physics. His first job there was to distribute office furniture in the building, and his second job was to load de-ionized water into the storage tank for the PDP. This was followed by more challenging jobs such as the first loading of heavy water. Gorrell worked in Building No. 777-M until 1956.

Gorrell recalled that a wide range of people worked at 777-M. Some had doctorates, others had Master degrees, while others had no higher education. Even so, no one was referred to as "Doctor" and there was little deference to position. Du Pont encouraged this sense of camaraderie. Gorrell recalled that

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[94] Wahl, "History, Savannah River Laboratory," 15.
[95] Norm Baumann, personal communication, October 19, 1999.

when Du Pont executives visited the building, they usually made an effort to learn everybody's names. Even so, this diversity was limited. In the 1950s, and certainly in 1953, there were no women and no African Americans within the building's work force.

For most workers at 777-M, the PDP was not only an experimental reactor, it was also a learning reactor. Few people at the time had any working knowledge of heavy water-moderated reactors, and at least some specialists had to be imported from Argonne National Laboratory. In addition to compiling new procedures for the operation of the PDP, the work had to be done very carefully, since so much was new. Calculations were an important part of this early work, and there were only limited computational tools available. These included slide rules, printed exponential tables, and Marchant machines. No modern computers were available for this work in the early 1950s.

Despite the careful work, there were still mishaps. Gorrell recalled that there was a safety rod drop test incident that occurred in the weeks before the PDP went on line. There were sixty-six cadmium safety rods, each 1" in diameter and 15'-0" long. Each rod had a motor, drum, and a clutch. All were designed to drop together if there was a scram. In theory, they would drop fast until they reached the last foot inside the tank, when the clutch would kick in and slow the final one-foot descent. In one of the scram tests, the snubbing voltage batteries were dead and the safety rods fell 15' to the top of the tank, followed by the cables. According to Gorrell, "there was enough blame to go around so that no one got fired."[96]

On another, more propitious occasion, Lewis Strauss, the chairman of the AEC, came to visit the building to view the PDP and all the instruments that surrounded it. One of the instruments on display was the "beetle," which was effectively a collection box with plates of electrical circuits, separated by paper. This was used to identify the presence of water vapor in the vicinity of the beetle. In a demonstration for Strauss, Gorrell took an eyedropper and added a drop of water to the beetle. This lit up a whole array of warning lights, causing Strauss to exclaim: "what hath God wrought."[97]

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[96] Tom Gorrell, personal communication, January 30, 2006.
[97] Ibid.

As might be imagined from Strauss's visit, the work at 777-M and the PDP was not only important to the future operation of the production reactors, but also was top secret. In fact, workers were discouraged from ever mentioning their work outside of Savannah River Plant. Research papers were not encouraged from work done at 777-M, unless it was a very compartmentalized part of the overall program. The number of published studies that came out of the work associated with the PDP was quite limited, and most of the sources used in this report were in the form of internal memos and letters between staff members. This remained true long after the first crucial year of 1953.[98]

Reactor Power Rise in the 1950s

Just as the PDP was important in the start-up of the first production reactor, it was also instrumental in the success of the power rise of the production reactors throughout the 1950s. This allowed for a greater production of plutonium and tritium than was anticipated. Beginning in 1953, but also continuing through the 1950s and beyond, the PDP was used to help solve physics problems associated with the production reactors. Even though the PDP was often only in use twenty percent of the time, the rest of the time was needed to process the test information.[99]

At its peak of operation in the 1950s, Building No. 777-M had an average of some thirty workers, ranging from highly trained engineers to operators or maintenance people with a high school degree. The breakdown has been estimated at about half engineering staff, and half non-technical people. The "operator pool" that supervised the PDP when it was in operation numbered around twelve.[100]

Among the people that worked around the PDP in the 1950s were Tom Gorrell, Ed Hennelly, Jack Crandall, George O'Neill, Jerry Carlton, and John Kennedy.[101] One of the more theoretical workers at 777-M during the mid-1950s was Norman Baumann, who worked virtually his entire career at SRL.[102] Baumann came in about the time that Gorrell was transferred out. In the years to come,

[98] Ibid.
[99] Norm Baumann, personal communication, October 7, 1998.
[100] Ibid.; Tom Gorrell, personal communication, January 30, 2006.
[101] Tom Gorrell, personal communication, January 30, May 19, 2006.
[102] Norm Baumann, personal communication, October 19, 1999.

Baumann became one of the more prominent people to work around the PDP.

Born in 1927 in Kansas, Norm Baumann graduated from Kansas University in Lawrence. Both he and his wife, Elizabeth, acquired doctorates and both came to work at Savannah River Plant around 1955. Baumann came to Savannah River in August of 1955 and was hired into the Experimental Reactor Physics Program at that time. He was immediately put to work designing new reactor charges, a program essential to the continued success of the production reactors, now working at high power.[103]

To give you some idea of the number of experiments run in the PDP during this era, it was noted in a later report that between 1953 and 1961, there were some 2,200 instances in which the moderator in the PDP was filled and drained, with only limited maintenance problems. In most instances, each of these drainage episodes represents a discrete experiment. Speaking of the PDP moderator, it is interesting to note that recharges to the heavy water moderator were necessary only twice in all that time.[104]

During the 1950s, especially during the period of reactor power increases, there was a strong connection between the Savannah River Laboratory and the Reactor Technology people that worked directly for the plant. The Laboratory was more theoretical, while Reactor Technology provided technical support for the daily operation of the production reactors. People were often trained in the Laboratory facilities, especially CMX, TNX, and Building No. 777-M, and were then transferred to Reactor Technology to assist in the operation of the production reactors.

Technically speaking, the people in Reactor Technology did not operate the reactors—that was the job of the Reactor Department. In one of many redundancies built into the Du Pont management of the plant, the Reactor Department actually ran the reactors, while Reactor Technology provided independent technical oversight. Reactor Technology personnel could not touch the controls or even give orders, but they had access to all the logs and acted as auditors of the entire operation. From this vantage point, they could make recommendations for changes in

[103] Ibid.
[104] Dunklee, *Heavy Water System*, 5, 31.

reactor operation, and these recommendations were usually followed.[105]

Out of all the organizations at Savannah River Plant, Reactor Technology had the closest function to that of the Savannah River Laboratory. As a result, when the production reactors needed extra staff for their Reactor Technology section, they would recruit people from the Laboratory. This often meant taking staff from 777-M. It appears that many 777-M people did not want to leave for Reactor Technology, but in the 1950s, the need was great and most individuals were dutiful about it. In 1956, Tom Gorrell was transferred to R Area, and many others followed the same route.[106]

During this period, there were important changes made to the tanks and the processes that occurred in 777-M. Sometime before the beginning of 1957, a "table top" was added to the PDP. It appears not to have been in place in 1953 as discussed earlier. At the time of initial operation, there were no plates in place and it was still possible to see the reactor top. Septifoils were exposed about two feet above the top of the reactor tank, and workers had to balance themselves on the exposed beams over the tank to make all necessary adjustments. Operators who were there that first year recall that it was not uncommon for glasses and pencils from the workers to fall directly into the tank. The appearance of the tank that first year is shown in a historic image.[107]

While it appears that no plates were installed in 1953, perhaps due to the urgency of the work that had to be done that year, some sort of reactor top plates were installed in time to be mentioned in the history of Project 8980, compiled by Du Pont in 1957. At the time, it was mentioned that the over-tank beams had been constructed at Du Pont's Wilmington Shops and were tested at New York Shipbuilding. Cover plates were bolted to these beams, and each cover plate had a hole to allow for the passage of tubes into the reactor. Blank plates were used when no holes were needed in the plates. After loading the vertical elements, the cover plates were sealed with pressure-sensitive

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105 Peter Gray, personal communication, October 13, 1999.
106 Tom Gorrell, personal communication, January 30, 2006.
107 Ibid.; Savannah River Operations Office, *The Savannah River Plant* (Aiken, South Carolina: Savannah River Operations Office, U.S. Department of Energy, 1978), 30.

lead foil tape or gasketed fittings to keep out dust and light water vapor.[108] As will be explained later, this was not the same "table top" present at the time of the building's demolition. That was a 1959 construction associated with the Heavy Water Component Test Reactor program.

By the middle and late 1950s, other alterations to the PDP occurred. Some are detailed in Du Pont records and some are not. For example, a modification in 1958 simply identified as Project S8-1042, and entitled "Increased Power-SR Reactor (777-M)" was completed at a final cost of $62,712. No further explanation or description of the project was provided.[109]

During this period, changes were also made to the SP to allow it to operate at higher power levels. In 1957-58, more shielding was added to the entrances of the SP-SE Room, and additional features were added to the SP complex so that it could operate at a maximum level of 10 kilowatts. Foremost among these was a pump and the piping for a small heat exchanger.[110] Under project S8-7005, dated 1959-60, a criticality alarm system was put into place in 777-M, as well as two other Laboratory buildings.[111]

By this time, the various devices used to measure neutron flux within the PDP and SE had become standardized. These included "ladders" containing gold pins, and various types of foils. Ladders were horizontal linear protrusions attached to assemblies. They were used to hold the pins needed to measure reactivity. Gold pins and foils, sometimes covered with cadmium, were often put inside fuel elements by means of a window; these too were sensitive to neutrons and could record neutron flux.[112]

All of these devices would prove useful, for the main purpose of the PDP and the SE in the later 1950s was to test new fuel and target assemblies scheduled for the production reactors. With

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[108] Du Pont, *SRP Engineering and Design History*, Vol. IV, 150-1.
[109] Du Pont, *SRP Engineering, Design, and Construction History of "S" Projects (1953-60)*, 863.
[110] Hood Worthington, "Operation of the Standard Pile at a Power Level of Ten Kilowatts," Letter to R. C. Blair, Manager, U.S. Atomic Energy Commission, Savannah River Operations Office, September 27, 1957.
[111] Du Pont, *SRP Engineering, Design, and Construction History of "S" Projects (1953-60)*, 871.
[112] Tom Gorrell, personal communication, May 19, 2006; Chuck Jewell, personal communication, May 22, 2006.

the constant rise of reactor power, it quickly became apparent that the original solid fuel element design, known as the Mark I, was grossly inadequate. Basically unchanged since the days of the Manhattan Project, the Mark I was succeeded by a number of different designs. These included hollow slugs, followed by the revolutionary tubular elements that went into general operation by 1956. Tubular elements even required a brand new manufacturing facility (Building No. 321-M), located fairly close to 777-M. All of these new elements had to be tested in the PDP and SP-SE before they could be released to the production reactors.[113]

PDP Work in the mid-1950s

There were many tests done in the PDP during this period, but the most important were related to solving the problems associated with the power increases in the production reactors. These tests had a number of facets, as various aspects of the vertical elements that entered a reactor were examined, both singly and together, to determine their overall effect within a reactor operating at higher power. One of the first tests, concerning enriched fuel rods in the PDP, began as early as January 1954.[114] This led to more elaborate tests on the effects of using quatrefoil assemblies with enriched uranium-aluminum slugs (also known as spiking elements) to increase the reactivity of natural uranium lattices and achieve high power levels. The buckling (reactivity) of such a spiking assembly was found to be four times greater than that of a quatrefoil with only natural uranium. As a result of these tests, spiking elements were determined to be useful with natural uranium loads and would produce a better flux distribution in a standard Q-foil lattice at high power.[115]

Another aspect of these tests involved the control rods, particularly the use of "weak" control rods in conjunction with enriched fuel. This led to tests on flux shapes created by

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[113] Norm Baumann, personal communication, October 19, 1999.
[114] H. E. Ostdahl, "Storage of Enriched Fuel Rods," Memorandum to J. B. Tinker, E. I. Du Pont de Nemours and Company, Explosives Department, Wilmington, Delaware, May 22, 1953, 1-2; Milton H. Wahl, "Memorandum: Enriched Fuel Requirements, Building 777-M," To J. D. Ellett, December 14, 1953.
[115] W. M. Heston, *History, Savannah River Laboratory, July 1, 1955 to June 30, 1956*, E. I. Du Pont de Nemours and Company, Explosives Department, Atomic Energy Division, Technical Division, Savannah River Laboratory, Aiken, South Carolina, November 22, 1957, 16-17.

using weak control rods with less than the standard amount of lithium-aluminum. The lithium-aluminum alloy would range from the "standard" percentage of lithium (generally 3.5 percent) to 1.0 percent in the weak control rods. These tests also discovered that both the radial and vertical flux shapes could be improved by using weak control rods. These tests led to the use of weak control rods, in conjunction with strong rods, in the production reactors.

Another problem studied in the PDP was the issue of thermal stresses on the side shield of the production reactors as the power was increased. This problem was initially addressed by taking buckling (reactivity) measurements on various enriched fuel lattice arrangements. This helped in the formulation of "blankets": the optimum outer ring of Q-foils and lithium-aluminum slugs needed to reduce the heat problems associated with the rise in reactor power.[116]

Another related issue was the testing of new fuel assembly designs that would be more efficient than the original Mark I solid fuel slug in common use when Savannah River began operation. In just a two-year period, from 1955 to 1956, PDP tests helped develop individual fuel assemblies, from the Mark III (the plate fuel assembly) to the Mark VIII fuel tube.[117] All of this work led to efficient designs for co-extruded tubes in the mid to late 1950s. In this manner, the PDP contributed to the success of the co-extruded fuel tube as a standard feature in heavy water reactors-- definitely one of the highest technical achievements at Savannah River.[118]

Other, somewhat related tests were common during this same period. Tests were done on possible changes to the reactivity of elements caused by removing heavy water from the elements (the resulting loss was found to be negligible). Moderator boiling studies-- simulating boiling in coolant channels-- were done in anticipation of such a problem in the production reactors. This possibility was not found to be a major problem.

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[116] Ibid., 16-18, 31.
[117] Ibid., 16, 25-26.
[118] Norm Baumann, personal communication, October 19, 1999; R. S. Campbell, "P.D.P. Extruded Tubular Target," Designed and drawn by R. S. Campbell, Building 777-M, E. I. Du Pont de Nemours and Company, U.S. Atomic Energy Commission, June 15, 1959.

As a result of all these tests, researchers at 777-M could determine which fuel and target arrangements worked best at high power. In general, it was found that spiking elements (enriched uranium fuel elements) and weak control rods were required to run the production reactors at optimum efficiency.[119]

There were other discoveries as well. The loss of moderator tended to increase reactivity, both in the flat and buckled zones of the reactor.[120] In all likelihood, this discovery led to the design and construction of the Resonance Test Reactor (RTR) in the years to follow.

SP-SE Tests in the mid-1950s

Most of the testing completed in the SP and SE during the 1950s was associated with the wider range of testing done during this period in the PDP. The SE was used to test a range of lithium-aluminum tubes to be used in the production of tritium. These, of course, were also tested in the PDP.

There were other projects as well. In the SP, there were tests on assemblies designed to irradiate cobalt, then being considered as a substitute for lithium-aluminum in the control rods. Even though cobalt was found to be an adequate substitute for regular control rods of 3.5 percent lithium-aluminum, it does not ever appear to have used as such until high flux operation, several years later. Other elements tested for their usefulness as tubular assemblies included uranium-233 and thorium-232.

Tests in the SE were also done on the negative effects of light water on the reactivity of lattices using natural uranium. As a result, it was possible to calculate the loss of reactor productivity that could occur with the introduction of light water into the reactor.[121]

Heavy Water Power Reactor Work, late 1950s – mid-1960s

When Savannah River was established in the early 1950s, there were no civilian power reactors in the United States, or anywhere else in the world, for that matter. Within just a few

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119 Heston, "History, Savannah River Laboratory," 16-18, 29.
120 Ibid., 29.
121 Ibid., 17, 32-34.

years, however, this situation was turned on its head. Nuclear power reactors became the promise of the future and the search was on for new and improved methods of producing electricity from atomic power.

One common saying in reactor work is that, to be successful, a water-moderated reactor has to operate with either "enriched fuel or enriched water."[122] This effectively means that a nuclear reactor has to have *enriched uranium* in order to use light water, or *heavy water* (enriched water) to use natural uranium. In North America, both possibilities were already in full swing by the middle of the 1950s. The Canadians had been interested in heavy water reactors since the days of the Manhattan Project. By the 1950s, the Canadians had the NRX reactor on the Chalk River, and were well on the way to producing power reactors that ran on natural uranium, moderated by heavy water.[123]

In the United States, the other "enriched" alternative was being explored, largely as a result of Admiral Hyman Rickover's nuclear submarine program. In an environment where light water was virtually unlimited, the Navy based its reactors on enriched uranium. This preference spilled over into the development of civilian power reactors, and by the middle 1950s, most plans for U.S. power reactors followed the Navy's example. The AEC, which oversaw all aspects of the nation's atomic program, both military and civilian, wanted to do further work on the possibilities for heavy water reactors within the nascent civilian nuclear industry. Since Savannah River operated with heavy water moderated reactors, it was the natural site for this study.[124]

As early as September of 1956, the AEC requested that Du Pont inaugurate a program to study heavy water moderated power reactors, in addition to its regular nuclear materials production program. A formal request was made to that effect in November 1956. At that time, it was specified that Du Pont would create a power test reactor to be called the Power Components Reactor. It was to be capable of producing 100 megawatts, and was scheduled for completion by mid-1962. Later, this time restriction was removed. The request also stated that most of the work was to be done at Savannah River by the SRL.

[122] Norm Baumann, personal communication, October 19, 1999.
[123] Peter Gray, personal communication, October 13, 1999.
[124] Norm Baumann, personal communication, October 19, 1999.

Under consideration were seven different reactor designs, all of which were heavy water moderated, using natural uranium fuel. Options were also to be considered for the use of pressure tubes or vessels, as well as the use of a hot moderator.[125]

This power reactor work at SRL began in 1957 with a survey of all feasible natural uranium, heavy water-moderated power reactor designs and lattices. By the time this survey was complete, in June of 1958, the AEC had changed the name of the program to "Heavy Water Components Test Reactor." At SRP, this mouthful was usually shortened to "Hector," based loosely on the acronym "HWCTR."[126]

This brief discussion is to provide some background for the great wave of changes that took place at 777-M, beginning in 1959. By that time, the SRL had decided that the PDP would be at the center of the experimental work on the new power reactor. It would help determine the nuclear parameters for the project, and it would help determine the fuel, target, and control rod arrangements needed for its operation.[127]

The first alteration was the modification of the "table top" over the PDP. The original table top, in place by 1957, was described as a series of stainless steel plate beams over the tank that were 18" high and 0-3/8" thick; the cover plates that rested on the beams were made out of aluminum and were 0-7/8" thick, each covering an area 6" x 7".[128]

This construction was extensively rebuilt during what was called the PDP Superstructure Work. The new tank top was designed to improve moderator conservation, and prepare the PDP for a series

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[125] E. I. Du Pont de Nemours and Company, *Savannah River Plant Engineering, Design, and Construction History of "S" Projects and Other Work, January 1961 through December 1964, Volume II,* Engineering Department, Wilmington, Delaware, Prime Contractor for United States Atomic Energy Commission, U.S. Contract AT(07-2)-1, March 1970, 60-61; E. I. Du Pont de Nemours and Company, *History of the Savannah River Laboratory; Volume III – Power Reactor and Fuel Technology* (Covers period from November 1956 to December 1983), E. I. Du Pont de Nemours and Company, Savannah River Laboratory, June 1984, 3.
[126] Du Pont, *History of Savannah River Laboratory, Vol. III – Power Reactor*, 6, 9; Du Pont, *SRP Engineering, Design and Construction History of "S" Projects (1953-60)*, 533.
[127] Du Pont, *History of Savannah River Laboratory, Vol. III – Power Reactor*, 9.
[128] Du Pont, *SPR Engineering and Design History*, Vol. IV, 151.

of full-scale studies on the various power reactor lattices.[129] This new tank top was described a couple of years later in a report on the moderator features of the PDP. The new tank top had stainless steel removable beams that were 19″ deep and 0-3/4″ thick, with the beams spaced 5-1/2″ apart. The beams were such that they could support 180 tons. The aluminum cover plates above the grid beams were set up with heavy water vapor seals. The plates were hinged, with gasketed lids that could be easily opened or even removed.[130]

Another feature of the new tank top was the way it was oriented. The sides of the top were not aligned with the walls of the room around the PDP, but were seriously offset. There was no apparent reason for this, and at present, it is simply not known why this was done.[131] Other alterations to the PDP during this transformation included cleaning the reactor tank and coating it with silicone. New element storage racks were also added.[132]

Alterations also occurred to the SP during this period. A new heat exchanger was added, as well as new shielding doors, to allow for a higher operating power from one to ten kilowatts.[133]

Construction of the PSE, late 1950s

Another addition to Building No. 777-M during this period was a brand-new reactor formally identified as the "Pressurized Sub-critical Experiment" or the "Pressurized Exponential Facility," but usually just referred to as the "PSE." The PSE was installed in 1958-59 along the west wall of the "standards room," the same room that contained the SP-SE adjacent to the east wall. The tank was ready for partial use as early as October 1958, and was finished in May of 1959. Water storage for this pressurized vessel was located in the west stairwell on the basement level.[134]

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[129] Du Pont, *History of Savannah River Laboratory, Vol. III — Power Reactor*, 10.
[130] Dunklee, *Heavy Water System*, 6.
[131] Peter Gray, personal communication.
[132] Du Pont, *SRP Engineering, Design, and Construction History of "S" Projects (1953-60)*, 573; 878.
[133] Du Pont, *History of Savannah River Laboratory, Vol. III — Power Reactor*, 10.
[134] Du Pont, *SRP Engineering, Design, and Construction History of "S" Projects (1953-60)*, 533-534.

The PSE was a pressurized tank 6'-0" high and 4'-0" wide. It was capable of withstanding 300 pounds of pressure per square inch, and was equipped with internal instruments to permit the testing of lattice patterns inside the tank. Its main purpose was to determine the precise characteristics of natural uranium fuel lattices in a heavy water moderator, at temperatures ranging from 100 degrees to 200 degrees Celsius.[135] It was designed to measure the operational boundaries of the HWCTR at high temperatures. At the time of its installation, the PSE was the only facility anywhere in the world capable of registering such readings.[136]

Over the next couple of years, the PSE performed a number of physics tests for the heavy water lattices at high temperatures, using uranium metal tubes and uranium oxide rod clusters. In 1960-61, it even did experimental work for the Swedish "R3/Adam" power reactor.[137] This work, however, did not last long. By 1962, when Chuck Jewell first came to work at 777-M, the tank was no longer used for any pressurized experiments.[138] It was deactivated in 1971.[139]

Other Additions, late 1950s – early 1960s

The late 1950s and early 1960s saw new traveling monitors installed in both the PDP and the PSE. A series of hand-drawn diagrams previously stored in 777-M indicate that these traveling monitors needed a few design changes before they would work effectively. Certainly by 1961, these monitors could adequately record axial flux distribution, and gamma compensation for the PSE.[140]

Another much large building change was the addition of a new neutron "counting room," for foils in nuclear tests. This was to be added underground at the basement level, off the northeast corner of the original building and was to be shielded with

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[135] Ibid.
[136] Norm Baumann, personal communication, October 19, 1999; Du Pont, *History of Savannah River Laboratory, Vol. III – Power Reactor*, 10.
[137] Ibid., 17.
[138] Chuck Jewell, personal communication, May 22, 2006.
[139] P. L. Roggenkamp, "PSE Reactivation," Memorandum to J. R. Hilley, Savannah River Laboratory, Technical Division, February 1, 1977.
[140] William J. Woodward, *A Traveling Flux Monitor for Exponential Piles*, E. I. Du Pont de Nemours and Company, Savannah River Laboratory, Aiken, South Carolina, AEC Research and Development Report, October 1961, 4.

concrete. The plans for this construction were drawn up in 1960, and it was built the following year. This room effectively replaced the old counting room, which was rendered unusable by the higher power level operation of the PDP and the other reactors in the building.[141]

The installation of the first computers in Building No. 777-M in the early 1960s may also have been related to the new counting room. These were IBM 650's and 704's that were used to do some of the more menial number crunching associated with the neutron tests. Soon it was found to be cheaper and often more accurate, to simply let the computers determine the results of an experiment, rather than run the experiment itself.[142]

Basics of the HWCTR Work

Among the first tests done in 777-M for the Heavy Water Component Test Reactor, was one to determine the best design for the prototype for the core.[143] The optimal design was found to be the "Case B-1," a large pressure vessel, with tubes of metallic uranium as fuel, and with hot heavy water used as both moderator and coolant. This type of reactor was projected to have the least technical problems of any of the possible alternatives.[144]

The other experimental physics work done at the PDP for the HWCTR project, included:

1. Determining in-hour equation for the heavy water reactors, with allowances for the effect of delayed photo-neutrons.
2. Determining better techniques for measuring fast-fission distributions.
3. Measurements of neutron age for various mixtures of light and heavy water
4. Determining the best power reactor lattice arrangement for HWCTR. It was noted that, "at the time these experiments were undertaken, there were no data on the reactivity of fuel assemblies with internal cooling channels."
5. Study of heavy water shields for power reactors

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[141] Peter Gray, personal communication, 17 May 2006; Du Pont, *SRP Engineering, Design, and Construction History of "S" Projects (1953-60)*, 803.
[142] Tom Gorrell, personal communication, January 30, 2006.
[143] Norm Baumann, personal communication, October 19, 1999.
[144] Du Pont, *History of Savannah River Laboratory, Vol. III – Power Reactor*, 3.

6. Study of metallic uranium fuel elements and uranium oxide fuel elements, specifically thin-walled uranium tubes, with zircaloy-2 as the cladding material. Part of this study included finding ways to make zircaloy more cheaply.[145]

By 1960-61, both the PDP and the SE were engaged in full-scale lattice studies associated with HWCTR. Twenty-one full reactor loadings were tested in the PDP, with natural uranium as the fuel; twenty-four loadings were done using uranium oxide as the fuel. Studies were also done in the SE to check metal fuel characteristics. In the course of this work, it was found that there were "discrepancies between the exponential and critical experiments," or in other words between the findings of the SE and those of the PDP. Also, studies were done in the SE on the effects of light water contamination. This sort of HWCTR work continued until at least 1963, long after the HWCTR went critical.[146]

The HWCTR work was perhaps the biggest mobilization of talent for a single program in 777-M since 1953, the very first year of the PDP's operation. Among the key 777-M and/or SRL people who worked on physics questions associated with HWCTR, were: E. O. Kiger, L. M. Arnett, Peter Gray, R. R. Hood, J. M. McKibben, Tom C. Gorrell, S. H. Kale, H. P. Olson, D. A. Ward, C. P. Ross, B. C. Rusche, C. D. Taylor, and V. D. Vandervelde.[147]

Operation of HWCTR and Its Aftermath

The test reactors within Building No. 777-M played an integral role in the development of the HWCTR, which was constructed in B Area within the Savannah River Plant. The test reactor, which was completed in 1961, had a core of 3'-3" diameter and 10'-0" tall, inside a 30'-0" vessel with outer coolant loops. The containment building was 70'-0" in diameter and 125'-0" high. HWCTR, also identified as Project S8-1086, went critical for the first time on March 3,1962, and ran at least intermittently until it was shut down for the last time on December 1, 1964. Soon after, it was placed on stand-by. The remaining program

[145] Ibid., 4-5.
[146] Ibid., 17, 38.
[147] Ibid., 64.

activities of the HWCTR Task Force were terminated in June of 1965.[148]

The results of the HWCTR program were useful, but limited. Parr Reactor in Parr, South Carolina, began producing electricity in April of 1963. Built by a consortium of local power companies that went by the name of Carolinas-Virginia Nuclear Power Associates, Parr was the first nuclear power plant in the Southeastern United States, and the only one in the nation to use heavy water as the moderator. To make this sort of nuclear power plant feasible, the AEC had contributed almost one-third of the funds required to build the plant.[149]

Parr Reactor did not start a trend, but rather ended it. Heavy water moderated power reactors never took off in the United States. Even though testing indicated that there could be corrosion problems with the zircaloy elements,[150] this was certainly not enough to stop the development of heavy water moderated power reactors. The real culprit was the general trend of the civilian nuclear industry, which by the early 1960s, was too far along the path toward light water and enriched uranium to seriously consider any other options.[151]

Even so, the end of the HWCTR program did not mean the end of all research into heavy water moderated power reactors at Savannah River. In 1963-64, there was work done in both the PDP and the SE for the French EL-4 Reactor, a gas-cooled and heavy water moderated vessel. A more ambitious program began in 1965, when the AEC inaugurated the Heavy Water Organic Cooled Reactor program, or HWOCR, as part of their study of "advanced-converter" power reactors. Because of the use of heavy water at Savannah River Plant, the SRL was involved in this program. Experiments continued into the use and corrosion problems associated with zircaloy elements. In the PDP, this new HWOCR program required mock-ups of burned up fuel tests, using both

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[148] Ibid., 6-7, 14, 23, 54-5; Du Pont, *SRP Engineering, Design, and Construction of "S" Projects (1961-64)*, 53.
[149] "Power Reactor at Parr Goes Critical," *Savannah River Plant News*, vol. XI, no. 5, April 5, 1963.
[150] Du Pont, *History of Savannah River Laboratory, Vol. III — Power Reactor*, 44, 54.
[151] Norm Baumann, personal communication, October 19, 1999; Peter Gray, personal communication, October 13, 1999.

depleted uranium and plutonium isotopes. Potential fuel assemblies were also tested in the SE.[152]

Even though the HWOCR program was cancelled in the spring of 1967, some of this same work continued in the AEC-AECL cooperative program set up for the development of heavy water power reactors. This became the Heavy Water Reactor program or HWR that was established in the summer of 1967 in Richland, Washington. Some of this work also continued in Building No. 777-M. One of the tests conducted in the PDP was element loading to test the effect of "strong asymmetrical positioning and particularly inserted control rods." Tests were also done to obtain "detailed flux profiles provided from bare and cadmium-covered gold pins." In the SE, there were tests to recover reactivity data about coolant boiling in light water-cooled lattice arrangements. By the late 1960s, however, HWR programs and other related work had largely petered out.[153]

Transplutonium Work at 777-M

Building No. 777-M was less engaged with the Transplutonium Program, at SRP than with the heavy water power reactor studies described above.[154] Even so, there were a number of building alterations that were proposed during that period that had some connection to the Transplutonium Program.

The Transplutonium Program began at Savannah River in the late 1950s, but were more fully developed in the late 1960s. Pushed by Glenn Seaborg, then chairman of the AEC, the Transplutonium Program was dedicated to the production of new man-made elements heavier than plutonium. This work began with the Curium I program in the middle 1960s, and continued through the Californium program in the late 1960s. Californium proved to be the heaviest of the new elements that were generated in the Savannah River production reactors.[155]

[152] Du Pont, *History of Savannah River Laboratory, Vol. III – Power Reactor*, 38, 49, 60, 67-68.
[153] Ibid., 70, 76.
[154] Tom Gorrell, personal communication, January 30, 2006.
[155] Mary Beth Reed, Mark T. Swanson, Steven Gaither, J. W. Joseph, and William R. Henry, *Savannah River Site at Fifty* (Washington, D.C.: U.S. Government Printing Office, 2002), 430.

In Building No. 777-M, one of the first proposed alterations associated with transplutonium, proposed as early as 1963, was the addition of a Van de Graaff accelerator, to be mounted vertically in the southwest corner of the PDP room. The initial proposal called for the use of the existing counting room, offices and laboratories, with a new control room added to the southeast corner of the building. The Van de Graaff accelerator was to have been used to determine cross-section measurements for neutrons in the energy range of ten Kev to several Mev. This was part of the proposed expansion of the SRL research program, and had importance for the Transplutonium Program as well.[156]

This Van de Graaff accelerator was considered for a number of years, but was never installed. Even though it would have been useful in measuring nuclear cross-sections during the production of californium, by the end of 1968, it was finally decided to make more conventional changes to the existing facilities, namely the PDP and the SP-SE complex.[157]

One new feature that was added to the building was the Resonance Test Reactor (RTR), later identified as the Lattice Test Reactor (LTR). This was constructed in the late 1960s as a direct part of the Transplutonium Program. The theory behind the RTR was that if you took away some of the heavy water moderator and put the vertical elements closer together, you could force the neutron spectrum to go to a higher level of energy, referred to as a "resonance region." This was some sort of intermediate stage between slow (thermal) neutrons and fast neutrons. A resonance reactor was thought to be useful in the Transplutonium Program because it offered a different way to deal with reactor neutrons. In the production of transplutonium elements, the goal was not to use neutrons for fission, but rather for the new elements to capture as many neutrons as possible on the road to making californium.[158]

[156] "Van de Graaff Accelerator, 300 Area – Building 777-M, Savannah River Plant, May 1963," E. I. Du Pont de Nemours and Company, DPST-63-188, revision 1.
[157] F. E. Kruesi, Letter to Nat Stetson, Manager, Savannah River Operations Office, U.S. Atomic Energy Commission, Aiken, South Carolina, December 6, 1968.
[158] Norm Baumann, personal communication, October 7, 1998.

The RTR tank was 10'-0" high with a diameter of 10'-0" and was situated beside the PDP. It was basically only two-thirds the scale of the production reactors, because it was assumed that it would need a smaller amount of material. It was designed to operate with a higher neutron speed, or a higher "trajectory" of neutrons, than would have been possible with thermal or slow neutrons.[159]

In the end, the RTR was not found to be particularly effective. High flux, which was still a slow thermal neutron program, was found to be more effective in the creation of californium than was the resonance reactor. In later years, when the reactor's name was changed to the Lattice Test Reactor, it was used in a more conventional manner to make precision measurements. In that capacity, it was basically considered a part of the PDP.[160]

Reorganization and Slow-Down, 1970s

Everything began to change for Building No. 777-M during the decade of the 1970s. First, there were changes in personnel and in management styles. These brought to the fore a greater concern for safety in the day-to-day operation of the facility. In all likelihood, this corresponded to the final perfection of the fuel and target assemblies as a result of two decades of testing in the PDP and SE, and in other Savannah River facilities. Even though other peripheral uses were found for the test reactor facilities in 777-M, with the successful completion of fuel and target testing, it soon became clear that the days of the PDP and the SE were numbered.

The 1970s saw a whole new group of people employed in 777-M. Among these was Peter Gray, who began work at Savannah River back in 1952, but was not transferred to Building No. 777-M until 1969. From that time until at least the middle of the 1970s, Gray was one of the management staff at 777-M.[161]

There were many others who came aboard during this same period. Charles E. "Chuck" Jewell was a regular during this era. Fred

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[159] Peter Gray , personal communication, May 17, 2006; Tom Gorrell, personal communication, January 30, 2006; Norm Baumann, personal communication, October 7, 1998; Chuck Jewell, personal communication, May 22, 2006.
[160] Norm Baumann, personal communication, October 7, 1998.
[161] Peter Gray, personal communication, September 15, 17, 1999; October 13, 1999; May 17, 2006.

Rhode, who worked in nearby Building No. 321-M, was also familiar with the 777-M facility.[162] In around 1970, the list of SP operators included Norm Baumann, C. L. Beeson, J. L. Jarriel, J. D. Spencer, D. J. Pellarin, V. A. Johnson, and J. D. Robertson. Among the many others who worked at 777-M during the 1970s, were: James M. Boswell, C. C. Ivey, J. K. Price, Polly Hill, Betty Wise, A. C. McPherson, P. B. Parks, A. A. Tudor, J. R. Bryce, R. L. Reed, S. E. Burdette, D. S. Cramer, W. G. Winn, N. H. Kuehn, W. E. Seiersen.[163]

The biggest shift to occur in personnel and in management style occurred in the early 1970s, when 777-M and in fact the entire Savannah River complex switched to a middle management style of operation. Trained managers were brought in to help run the facility, and this led to a reorganization at 777-M. In 1971, J. L. Jarriel was made overall head of the SP-SE complex, while C. E. Jewell was placed over the PDP-RTR operation.[164]

This was accompanied by a general change in the day-to-day operation of the building, with more detailed operational logs and checklists. There were checklists and approval sheets for the SP-SE facility, an SP-SE log, and SP Irradiation Request forms. In the case of the SE, there were lattice change requests, checkout and pump-up authorizations, multiplication measurements, and forms for the moderator system, all of which required a re-training of the operators.[165] There were also SP-SE Maintenance Logs and By-Pass Logs. Undoubtedly, there were similar changes to the PDP operation.

There is some question as whether these changes represent a real break with the past operation of the building facilities, or whether more is simply known about them solely because they are more recent and the pertinent forms have survived. Without a doubt, there were earlier forms that governed the operation of the building facilities. These may have been discarded as unnecessary after the 1970s. Even so, there does appear to have

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[162] Fred Rhode, personal communication, June 12, 2003.
[163] General information from 777-M work sheets dated to 1970s, including a notebook entitled "SP-SE Goodies," on file, SRS History Project, Temporary Curation Facility.
[164] Norm Baumann, personal communication, October 19, 1999; Peter L., "Functions and Responsibilities of EPD Engineering Group," General Memorandum, Savannah River Laboratory, Technical Division, January 7, 1971.
[165] Forms on file, SRS History Project, Temporary Curation Facility, e.g. SE Lattice Change Requests, 1971-77; DPSTOM-7, vol. 1, revision 5, date: 6/78.

been a tightening of the overall operation of the PDP and the SP-SE in this decade, and there is documentation to support that. In the case of the SP, there had previously been monthly checks of the neutron source material; in the 1970s the inspections were daily.[166]

Safety was one of the big issues that drove this move toward greater documentation. This was a general plant-wide concern throughout this decade and in the years that followed. But another factor was that the operation of the PDP and SP-SE was starting to wind down. By the early 1970s, there was a sense that the optimum arrangements of the fuel and target elements had been achieved, making the original function of 777-M less urgent. By the 1970s, the Mark 22 element was recognized as the optimum tritium producer, just as a combination of Mark 14, 16, and Mark 30 series was recognized as the best for the production of plutonium. Increasing sophistication, not only of the assemblies, but also the lattice arrangements, reached a certain plateau by the 1970s. And the PDP and the SP-SE had played a significant role in that development. Soon it was obvious that the original function of the building had reached its limits, but it was not yet clear what the future would bring.

During this period of transition, Building No. 777-M was considered as a possible site for a Californium Irradiation Facility (CIF). Californium, or Cf-252, was the end product of the Transplutonium Program that had been on-going at Savannah River since the 1960s. Californium had been created largely as an experiment, but after the fact, much work was done at Savannah River to find uses for this new man-made element. Within Building No. 777-M, consideration was given to using the PSE tank for storing californium during this period. The PSE tank, which had been retired from its original function in 1971, was proposed for neutron radiography and activation experiments associated with californium. Such experiments in the SP would have required a run of over an hour at eight kilowatts of power. Similar experiments would have been easier in the PSE, and could be done there without an operator on constant call. To re-fashion the PSE for this purpose, it was suggested that the tank top be replaced with another design, using light water in the

[166] Norm Baumann, Peter L. Gray, and J. L. Jarriel. "Proposed Modifications to SP Operations," Memorandum to P. L. Roggenkamp, Savannah River Laboratory, Technical Division, February 5, 1975, 1-2, 5.

vessel for adequate shielding.[167] By 1978, it was proposed that the CIF would use a 3 mg californium source and be situated in the PSE tank that was "originally designed as a pressurized subcritical reactor."[168]

Despite these plans, it appears that there was never a formal CIF facility as planned. The PSE tank did, however, hold a "californium shuttle," which was used to provide neutrons. The shuttle was a californium pulse-neutron generator, which was usually kept inside the PSE tank, from which the top had been removed. The shuttle fit on top of the tank.[169]

During this transitional period, there were even connections with outside irradiation work. In 1978, Dr. Ignun Hahn of Benedict College expressed an interest in using the 777-M facilities to determine trace amounts of impurities in the air and rainwater samples from Columbia, South Carolina.[170] It is not certain whether the facilities were ever employed in this manner. If they were, it was certainly not for long.

Throughout the late 1970s, there was increasingly less activity in both the PDP and in the SP-SE complex, and this decline can be discerned from the operation logs. In fact, according to the SP-SE Log, the last reactor run in those vessels was made on 23 March 1979, and the entire building went on stand-by in late May and early June of the same year.[171] Effectively, the 777-M facility ceased experimental work in 1979.[172]

To some degree, the PDP and the SP-SE facilities in Building No. 777-M were killed by their own success. Both reactor facilities contributed to the final success of the Savannah River mission, which was to produce plutonium and tritium for the nation's nuclear arsenal. The facilities at 777-M were instrumental in the testing of both the nuclear properties of Savannah River

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[167] P. L. Roggenkamp, "PSE Reactivation," Memorandum to J. R. Hilley, Savannah River Laboratory, Technical Division, February 1, 1977.
[168] C. E. Jewell and W. G. Winn, *Safety Analysis of the 252-Cf Irradiation Facility in Building 777-M*, E. I. Du Pont de Nemours and Company, Savannah River Laboratory, Aiken, South Carolina, October 1978, 5-7.
[169] Chuck Jewell, personal communication, June 14, 2006.
[170] E. J. Lukosius, "Discussion with Dr. Hahn," Memorandum to E. I. Baucom, Technical Division, Savannah River Laboratory, August 4, 1978.
[171] SP-SE Log (with entries from January 15, 1971 to April 30, 1979, when Building 777-M went on standby), 255.
[172] Chuck Jewell, personal communication, May 22, 2006.

production reactors, and the vertical fuel and target elements that had to go into these reactors. Without the PDP and the SP-SE, this achievement might have been compromised.

Another factor played a role in the demise of the PDP and SP-SE. This was the rise of increasingly powerful computers, first introduced into the nuclear production at Savannah River in the early 1960s, and upgraded with increasingly frequency in later years. By the 1970s, such computers were powerful enough to run all of the numbers needed to determine the flux calculations for most nuclear problems that might arise at Savannah River. They were also far less expensive to run than the experimental physics tanks housed in 777-M. By the 1970s, computers were clearly preferred for such work over active test facilities like those in 777-M.[173]

Transition to 777-10A, 1980s-1990s

On June 10,1980, a meeting of the Laboratory Services Division (LSD) was held to review the status of Building No. 777-M. At that time, it was determined that the Savannah River Laboratory would transfer the building directly to Savannah River Plant. All Laboratory staff would vacate the premises, and any future criticality responsibilities in 777 would be assumed by 300-Area personnel.[174]

During this period, barriers were put up to isolate the PDP and SP-SE tank and control room areas from the rest of the building. This would allow occasional experiments to be conducted, and these occasional experiments occurred right up until 1988, when the PDP was used for the last time.[175] The rest of the building, however, was now free for other functions, and this was soon the home of Savannah River Plant's Audio-Visual Services. For this reason, the formal building designation was changed from 777-M, with its implied emphasis on manufacturing, to 777-10A, which suggested a more administrative function.[176]

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[173] Tom Gorrell, personal communication, January 30, 2006.
[174] D. T. Rankin, E. Nomm, R. L. Reed, D. J. Reif, and R. D. Lee, "Minutes: SRL Criticality Review Committee, June 10, 1980," Technical Division, Savannah River Laboratory, June 13, 1980.
[175] Norm Baumann, personal communication, October 7, 1998.
[176] Tom Gorrell, personal communication, January 30, 2006.

Beginning in the early 1980s, most of the offices and basement facilities of 777 were turned over to Audio-Visual Services, which used the building both as a studio and as a storage facility. Audio-Visual Services, in fact, was a new creation; earlier, this sort of work at Savannah River had been done by the Training Department. Audio-Visual was not to be confused with Photography, at least not during this period. In the 1980s, Audio-Visual Services and Photography were two separate organizations. Only since the closure of 777-10A have Audio-Visual and Photography been merged into "Photography and Video Documentation Services," sharing the same building and the same supervisors.[177]

In 1981, when Audio-Visual first occupied Building No. 777-10A, the facilities there included a 30'0" x 30'0"studio, various smaller television and video studios, editing suites, and facilities for audio recording. Initially, the purpose of Audio-Visual Services was to facilitate video training for the plant. Within a year or so, the purpose of the organization had gone from training, to video production for internal and external use. Later, the name was changed to Video Services. They produced everything from safety films, technical films for production, and three-dimensional animation. They also housed an extensive library that included old 16mm safety films from the 1940s and 1950s, as well as modern videos.[178]

Video Services was not the only new tenant in Building No. 777-10A. In 1982, the Site Utilities Department (Electrical Power Department) moved into ground floor offices in the front or east side of the building. Site Utilities occupied this area until 1999, when all tenants had to vacate the building.[179]

In the middle of this transitional period for the building, there was another transition of far greater impact to Savannah River. In 1987, Du Pont decided not to renew its contract with the Department of Energy (DOE). The AEC was a predecessor agency to DOE. Two years later, Westinghouse Savannah River Company became the prime contractor at SRP after Du Pont departed and the name of the production facility changed from Savannah River Plant to Savannah River Site.

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[177] John Brecht, personal communication, July 19, 2006.
[178] Ibid.; Tom Kotti, personal communication, July 20, 2006.
[179] Tom Kotti, personal communication, July 20, 2006.

During the two decades that Video Services occupied 777-10A, they stayed abreast of the latest technological innovations. In the mid-1990s, they were among the first in the Southeastern United States to work with non-linear editing, done by computer. This period, which corresponded to the early years of Westinghouse, probably represented the peak of Video Services, when some sixteen staff members worked in 777-10A. At that time, Video Services provided a wide range of services to Savannah River Site: everything from employee communication films, emergency response work, and safety videos. At that time, the production facility was considered one of the largest in the region.[180]

During this period, which was clearly peripheral to the original mission of 777-M, there was a slow dismantling of the original facilities. By 1998, if not before, the heavy water had been removed from the PDP tank system, and some of the auxiliary equipment had been removed from the building. The tank itself and the top casing remained in place until late June of 2005. In 1999, both Video Services and Site Utilities moved out, when it became clear that the building was destined for future decommissioning and possible demolition.

In 2001, Building No. 777-M, the Physics Assembly Laboratory, was evaluated for its National Register of Historic Places eligibility and was considered to be historically significant for its role in the Cold War and as an excellent example of twentieth-century engineering. At that time, it was considered feasible to preserve the building at minimal operational costs.[181] In 2005, SRS elected to demolish the facility. The PDP tank top, its control room console and panels, and the SP/SE control console and panels were removed in late June of that year for potential future interpretation of the building's Cold War historic mission and the building itself was demolished by year's end.

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[180] John Brecht, personal communication, July 19, 2006.
[181] K. O. Darden, "Deactivation Plan, 777-10A Physics Laboratory," Westinghouse Savannah River Company, Savannah River Site, Aiken, South Carolina, May 9, 2001, 5.

PART II. BUILDING DESCRIPTION

Building Setting and General Description

Building No. 777-M was constructed at the southwest edge of the combined 300 and 700 areas, also known as M and A areas. M and A areas, near the northern perimeter of Savannah River Plant, housed the plant's administrative offices, the Savannah River Laboratory, and the plant's fuel and target manufacturing area. The building faced Road D.

In terms of general construction, the basic building details were comparable to other SRP buildings. The foundation was reinforced concrete, as was the superstructure around the PDP. Structural steel was used as superstructure in the other parts of the building. The roof consisted of open web roof joists, and the exterior walls were formed with sheets of flat cement asbestos board, known as "Transite™."[182]

In plan, the building was L-shaped, with a multistory reactor wing that was boxlike in shape on the west side, and a one-story laboratory wing projecting to the east. Designed to be functional, the building was more of an envelope covering its installed equipment. The personnel entry was located on the east side of the laboratory wing, facing the parking lot. The reactor wing covered an area 83'-2" x 128'-8"; the laboratory wing, 52' x 145'-11". The entire building had a full basement, but there was also a sub-basement underneath the PDP. Total floor space, including corridors, was approximately 53,900 square feet.[183] Only the laboratory wing had windows.

The building had its own perimeter fence, parking lot, and guardhouse. The guardhouse was added after the construction era to provide easy access to the building for the 777-M staff.

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[182] Du Pont, *SRP Engineering and Design History*, Vol. IV, 135.
[183] Ibid., 130-135; Voorhees Walker Foley and Smith, *Savannah River Plant Engineering and Design History, Volume II of II, Design Development and Description of Buildings, Equipment and Facilities (Appendix B)*, New York: Voorhees Walker Foley and Smith, Subcontractor for Engineering Department, E. I. Du Pont de Nemours and Company, Wilmington, Delaware, Prime Contractor for United States Atomic Energy Commission, U.S. Contract No. AT(07-2)-1, Du Pont Project 8980, Subcontract No. AXC-6-1/2, December 1, 1953, 162-163.

Reactor Wing

The reactor wing, in particular the PDP area, contained six levels, identified by their distance above and below ground level. The lowest level, minus 37′-3″ (usually written –37′-3″), was the Moderator Storage Tank area, with all of its various process piping and valve work. Above this was Level –28′-3″, known as the Sub-Basement Experimental Area. Level –15′-3″ was the Basement Experimental Area; this was the level of the PDP reactor tank (the base of the tank rested on this level) and the moderator recovery facilities. This level also contained the Basement Service Area, which had electrical controls for the PDP, including the control rod drives and emergency power equipment, all within a shielded area. The main floor of the reactor wing, located at Level 0′-0″, contained the PDP reactor top, as well as the moderator loading and unloading station, and storage area for the control rods. Also located at Level 0′-0″ was the PDP control room.

Above the main floor was the Mezzanine Area (Level +13′-1″), which contained the moderator purification facilities, the reactor vent, and a walkway. Also at this level was the Fan Room, with heating and ventilation equipment for the reactor area. The upper-most level (+27′-0″) consisted of two areas: the Upper Floor Experimental Area and the Upper Floor Storage Area. The former provided access for loading the PDP reactor and handling the fuel samples. It also contained the sheave racks for the cable-operated rods and the safety rod drive motors. The latter, the Upper Floor Storage Area, contained racks for the storage of the vertical elements for the reactor, and had access for the fuel elements to be lowered to the assembly and disassembly area. The whole upper floor area was also served by a motorized bridge crane that operated at this level.[184]

Within the reactor wing, there was also the Standard Pile Area. This consisted of the SP experimental room located at Level –15′-3″; the upper experimental room at Level 0′-0″, with a monorail one-ton hoist; the SP Nuclear Physics laboratory (-15′-3″), as well as the SP control room and operations office.

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[184] Voorhees Walker Foley and Smith, *SRP Engineering and Design History, Vol. II*, 159; Du Pont, *SRP Engineering and Design History*, Vol. IV, 130-133.

Also within the reactor wing was the Assembly Area, where fuel loadings were prepared for both the PDP and the SP. This area was shielded from the reactors for worker safety. The basement portion of this area contained the SP assembly area, a vault for critical material storage, a compressor room for refrigeration facilities, and an elevator equipment room. The ground level of the Assembly Area contained the main PDP assembly equipment, storage racks for loaded fuel tubes, a covered loading dock, and an elevator. The +16'-0" level had steel frames used to hang the fuel tubes.

The reactor wing was well preserved with little changes over time. Much of the process area was used for equipment and incidental storage related to the building's use under Site Video Services. Even the SP/SE reactor room was used for storage. Two balances used for making weight determinations were stored there.

In 1981, when Site Video Services began their occupation of the building, some changes occurred but most of these were sympathetic to the building's historic fabric. An AV Studio, 30'0" x 30'0" was positioned in the available space between the PDP reactor room and the SP/SE reactor room on the first floor. No changes were made that appear to have affected the integrity of that area. However, the SP/SE control room on the north side of the building was altered. The control panels for those test reactors were located in a room accessed from the main corridor in the laboratory wing. When Site Video Services moved into the building, this area was converted into a sound room shown on the photo key as A128. An edit room and video room were also created in this area. The conversion was accomplished sensitively, using partition walls. All original control room equipment related to the SP/SE reactor remained preserved in place. Documentation photography of this control room area took place after the partition walls were removed.

Laboratory Wing

The laboratory or office wing of the building had just one story at ground level, but also had a full basement across the entire wing. The main floor featured a central corridor flanked on both sides by laboratories and other purpose rooms. There was a dark room, a counting room, an instrument repair shop, a Health Physics room, lunchroom, men's locker room; toilets for men and women, and a janitor's closet. The ground floor contained seven offices and three labs for chemical, mechanical, and electronics work. In addition, the basement level contained service rooms for the air conditioning, hood vent fans, and various piping. It also contained an SP Neutron Beam Room for conducting beam tests from the neutrons provided by the SP. There was a balance room for making sensitive weight determinations.[185]

Unlike the reactor wing, the laboratory wing experienced considerable change when it was adapted for office use. Installed equipment was removed from the shops and laboratories. Floors were carpeted and ceilings modified with drop ceilings using acoustical tiles. The below grade area was also modified. The counting room added in the early 1960s in an offset manner to the northeast corner of the building was adapted for reuse as a conference room probably in the 1980s and was outfitted accordingly. Also a cluster of partition walled offices were built out between the counting room and the reactor wing area during that period.

Test Reactor Descriptions

Process Development Pile (PDP)

The large PDP complex was situated in the southwest corner of the reactor wing. The PDP reactor, moderated by heavy water, was a critical facility for reactor physics studies at low power levels. As an experimental reactor, it was designed for maximum flexibility, with a wide range of lattice components and arrangements. The tank itself was fashioned out of Type 304 stainless steel and was 15′-6″ high with an interior diameter of 16′-2″. The wall of the tank was 1/2″ thick; the bottom of the tank was 1″. The tank was designed to be filled with moderator to a height of 15′-3″, holding a volume of 3,150 cubic feet. In 1953, when the reactor was first put to use, it was still possible to see the top of the reactor tank. By 1957, when the official Du Pont design and engineering and construction histories were compiled, the reactor top was described as being covered with a tank top that measured 20′-0″ x 20′-0″ x 2′-0″. There were sixty-two support beams, topped by cover plates that

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[185] Du Pont, *SRP Engineering and Design History*, Vol. IV, 133-134; Voorhees Walker Foley and Smith, *SRP Engineering and Design History, Vol. II*, 159-160.

were 7/8" x 6" by various lengths.[186] The reactor top allowed a number of different lattice spacings, a versatility that was useful for producing different products in the reactor.

The vertical elements that went into the PDP consisted of 2400 fuel tubes placed into 606 quatrefoils, or Q-foils, each with a bundle of four fuel tubes. This allowed for a total of 105 tons of fuel to be placed inside the reactor. In addition, there were sixty-one "C" (control rod) cluster assemblies, each with five lithium-aluminum alloy control rods and two cadmium control rods. Ten of these assemblies were operated remotely; fifty-one were positioned by hand. There were also 120 safety rod assemblies, including sixty units for shutdown rods and two units for source rods.[187]

Reactivity within the PDP tank was controlled by three different systems, each supplied with 1"-diameter cadmium-sheathed rods. The first system consisted of the control rods, which could be positioned at any height within the reactor. The second system was comprised of the safety rods, which could be dropped into the tank within 1.5 seconds in the case of a "scram," or other emergency nuclear event. The third system consisted of the shutdown rods, located in four banks, each independently controlled.[188]

There were three different types of motor drives for these vertical elements. The "A" motor drive powered the control rods. The "B" motor drive operated the safety rods. The "J" motor drive controlled the shutdown rods. Among all of the heavy water-moderated reactors at Savannah River, the shutdown rods were unique to the PDP. They were added to reactor control as an extra measure of safety.[189]

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[186] Albert E. Dunklee, *The Heavy Water System of the Process Development Pile*. Experimental Physics Division, E. I. Du Pont de Nemours and Company, Savannah River Laboratory, Aiken, South Carolina. AEC Research and Development Report, DP-567, June 1961, 5; Du Pont, *SRP Engineering and Design History*, Vol. IV, 137; B. H. Mackey, "Reactor Safeguards – PDP," Letter to Curtis A. Nelson, Manager, U.S. Atomic Energy Commission, Savannah River Operations Office, Augusta, Georgia, February 26, 1953, 6.
[187] Du Pont, *SRP Engineering and Design History*, Vol. IV, 137.
[188] Dunklee, *Heavy Water System*, 6.
[189] Du Pont, *SRP Engineering and Design History*, Vol. IV, 137-137; Norman Baumann, personal communication, October 7, 1998; Chuck Jewell, personal communication, May 22, 2006.

The material that made reactivity possible in the PDP was the heavy water moderator, which had its own system for entering and leaving the reactor tank. The main equipment for the PDP moderator system consisted of the two storage tanks below the PDP, the pumps and the piping between the storage tanks and the reactor tank, and the de-ionizing controls. The auxiliary equipment consisted of a heat exchanger loop for heating and cooling the heavy water, a hot air blower and refrigeration system for drying the entire moderator system when not in use, a leak detection system, and last but not least, the system control and operating instruments.[190]

The key ingredient of the moderator system was the heavy water moderator itself. The PDP moderator system is believed to have originally held 100 tons of heavy water, but this was soon upped to 110. This heavy water was stored in two aluminum tanks located in the sub-basement. Each tank was capable of holding 13,000 gallons. The PDP could be loaded from these tanks in less than thirty minutes, at levels ranging from 3'-0" inside the tank, to 15'-3". Filters installed throughout the system captured small particles, and there were resin beds and ion exchangers to capture the smaller impurities.[191]

Within the PDP system, ionic cleanliness was important, since ionic contamination could cause corrosion. Ionic purity was achieved with an ion exchange system that maintained an electrical resistivity of approximately three megohm-cm, through the use of a mixed-bed ion exchange column. This system could de-ionize heavy water at the rate of fifteen to twenty gallons per minute.[192]

As a rule, the PDP reactor tank was filled and emptied remotely by means of a moderator system control panel, located in the reactor control room. This panel had indications for tank liquid levels, valve positions, moderator conductivity, and moderator temperature.[193] Other aspects of the PDP were also managed from this control room, usually by at least two operators. One operator remained at the console with the main

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[190] Dunklee, *Heavy Water System*, 5.
[191] Dunklee, *The Heavy Water System*, 2, 13, 36; Peter Gray, personal communication, May 17, 2006; Norman Baumann, personal communication, October 7, 1998; Du Pont, *SRP Engineering and Design History*, Vol. IV, 153.
[192] Dunklee, *The Heavy Water System*, 11, 18.
[193] Ibid., 13.

instruments; the other did micro-managing of the control rods at the "trim panel." Among the measurements monitored within the PDP control room, there was a Low-Level Neutron Measurement, which sounded with an audible pop every time a neutron was detected. There was also a High Level Neutron Measurement, provided by a group of ion-chamber neutron detectors around the reactor. This information was provided to a neutron panel in the control room, and would set off a "scram" if necessary. Moderator Temperature Measurement was established by thermocouples within the reactor. Moderator Level and Flow Control was managed through the "graphic panel" in the control room.[194]

SP-SE Test Reactors

The SP-SE complex was situated in the northwest corner of the wing. Like the PDP, six-feet thick concrete walls shielded the SP and SE tanks. The surrounding exterior walls were four feet thick. The SP-SE reactor room itself was 16'-0" wide, 35'-0" long, and 30'-0" high. This space was divided into upper and lower rooms by a steel grate floor at Level 0'-0". The SP or Standard Pile, was located along the eastern wall of the lower room, with the tank base resting at level minus 15'-3". The SE, or Exponential pile, was situated directly above the SP, with the top of the SE tank located at Level 0'-0".[195]

The SP and the SE, though usually operated in tandem, were very different reactors. The SP, based on a General Electric design, was graphite-moderated, and water-cooled when necessary. It was a reactivity testing device and a source of neutrons for the SE located directly above it. The SP reactor was fueled by enriched uranium. The fuel core was a hollow cylinder inside a five-foot graphite core. The core consisted of sixteen assemblies evenly spaced around the annular chamber. A four-foot graphite cube on the east side of the SP formed a thermal column that was isolated from the core by a layer of cadmium rods. This provided access from the SP into the neutron beam room immediately to the east. Neutrons from the SP also entered

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[194] Du Pont, *SRP Engineering and Design History*, Vol. IV, 141-143.
[195] J. L. Jarriel, C. E. Ahlfeld, and J. P. Church, *Safety Analysis of the SP/SE Experimental Complex*, E. I. Du Pont de Nemours and Company, Savannah River Laboratory, Aiken, South Carolina, May 1976, 13-15.

the SE immediately above by means of a 17″-high cylindrical graphite pedestal situated on top of the SP.[196]

The SP core had a reactor fuel container in the shape of an annular aluminum can. This can had an interior diameter of 12″, an outside diameter of 18″, and a length of 18″. It could hold sixteen fuel rods, as well as the light water coolant. The fuel rods were loaded into the container through a slot in the north side of the reactor. Fuel for the SP usually took the form of small uranium-aluminum alloy disks, clad with aluminum. Each disk was around three inches in diameter and 0.075″ thick, with half-inch holes in the center. These disks were spaced evenly on aluminum rods 15 inches long, and were separated by aluminum washers.[197] Informally, they were referred to as "shish kabobs."[198]

There were a number of instruments to monitor the progress of the SP operation. There were five ionization chambers used to detect high and low neutron levels. There were also flux level monitors. Much of this instrumentation, like the reactor itself, was designed by General Electric.[199]

The SE or Subcritical Experiment (also known as the "exponential tank" or "exponential pile") was an exponential tank with a flexible lattice arrangement that operated in conjunction with the SP. The SE was separated from the SP, its neutron source, by a cadmium shutter.[200]

Unlike the SP, which was a graphite reactor, the SE was a heavy water-moderated facility. The tank was 7′-0″ tall, with an interior diameter of 5′-0″. The vessel wall was three-eighths

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[196] Ibid., 15; Peter Gray, personal communication, May 17, 2006; J. P. Church, "SPCode: An Accident Analysis Code for the Standard Pile and the Nuclear Test Gage." Memorandum to P. L. Roggenkamp, Savannah River Laboratory, Technical Division, May 27, 1976, 2; J. K. Price, G. F. Merz, F. J. McCrossen, and J. D. Spencer, *Operating Manual and Procedures, SP-SE Complex in Building 777-M*. E. I. Du Pont de Nemours and Company, Savannah River Laboratory, Aiken, South Carolina, June 1978, 9.
[197] Jarriel et al., *Safety Analysis of the SP/SE*, 15-20.
[198] Chuck Jewell, personal communication, May 22, 2006.
[199] Du Pont, *SRP Engineering and Design History*, Vol. IV, 143; Jarriel et al., *Safety Analysis of the SP/SE*, 29.
[200] Baumann, personal communication, October 7, 1998; Gray, personal communication, May 17, 2006; Du Pont, *SRP Engineering and Design History*, Vol. IV, 130.

of an inch thick, with the base of the tank three-quarters of an inch thick. The sides were lined with a one-sixteenth inch layer of cadmium, and a two-inch layer of thermal insulation. The SE tank top was constructed to accommodate seven-inch triangular pitch lattices. The SE moderator system was served by a 1,000-gallon stainless steel storage tank (and two auxiliary tanks) and a twenty-five gallon-per-minute submerged pump, located at the minus 15′-3″ level in the SP room. Usually holding heavy water, the system could pump light water, depending on the experiment required in the SE. The SE tank could hold specially sized quatrefoils, septifoils, and fuel tubes, similar to those used in the large reactors, except for their shorter length.

An elaborate health monitoring system was installed in 777-M to cover both the PDP and the SP-SE. A total of twenty-two ionization chambers were situated in the reactivity areas and around the building to check for radiation leaks. Interlock systems prevented access to either the PDP or the SP-SE when the reactors were in operation. There was also a scram system in the unlikely event of a nuclear mishap.[201]

PART III. SOURCES OF INFORMATION

A. Engineering Drawings and Plans:

The as-built construction details for Building No. 777-M come from three basic sources. Two were produced by E. I. Du Pont de Nemours and Company, the main AEC contractor for the plant: *Savannah River Plant Engineering and Design History, Volume IV of VI; 300/700 Areas and General Services and Facilities* and *Savannah River Plant Construction History, Volume IV of IV; Construction 300-M, 400-D, 700-A, and 500/600/900-G Areas*. The third was produced by one of Du Pont's major subcontractors, Voorhees Walker Foley and Smith: *Savannah River Plant Engineering and Design History, Volume II of II, Design Development and Description of Buildings, Equipment and Facilities*. Du Pont was the prime contractor for both the construction and operation of Savannah River Plant, and had direct responsibility for the plant and its production. Du Pont drew up most of the reactor details pertinent to the building. Even so, Du Pont used a number of subcontractors in the course

[201] Jarriel et al., *Safety Analysis of the SP/SE*, 31-32, 37, 50; Du Pont, *SRP Engineering and Design History*, Vol. IV, 139, 143.

of constructing the plant, and one of the main subcontractors was the firm of Voorhees Walker Foley and Smith. This firm, under Du Pont supervision and direction, provided much of the final design to the building.

Twenty-three engineering drawings were photocopied for this documentation. They show the building's elevation and plans. The main drawings associated with the test reactors are also provided. These were used with the histories cited above to describe the building and its reactors. The originals of these drawings are currently on file at Savannah River Site's "Document Control," located in N Area (Central Shops).

B. Early Views and Historical Data:

SRS maintains a large and rich collection of historic views that show the 777-M, Physics Assembly Laboratory, from its construction to its demolition. Some of these views are included in the Appendix along with isometric drawings produced by Du Pont to show how the test reactors worked. All views are dated and captioned. The historical data comes from a variety of sources cited in the Bibliography below.

Special note needs to be given to the site histories. Du Pont and most of its major subcontractors compiled histories of their respective contributions to the Savannah River Project, and many of these histories convey the data found in the context. They provide the best documentation available for the design and construction of the buildings, equipment, and processes used in the first wave of construction at Savannah River. Among the sources used here are Du Pont's separate histories for engineering and design and for construction (*Savannah River Plant Engineering and Design History* and *Savannah River Plant Construction History*). The primary Du Pont subcontractors most closely associated with Building No. 777-M, were Voorhees Walker Foley and Smith and American Machine and Foundry, both of which compiled engineering and design histories of their contributions, including the work they performed on 777-M.

Finally, the Atomic Energy Division Records associated with the Du Pont Company, including SRS-related materials, are held by the Hagley Museum and Library, located in Wilmington, Delaware. This record group has information about Du Pont's activities from the Manhattan Project era to the Cold War, and a finding aid has been produced for the collection.

C. Interviews:

The following extremely knowledgeable former and current SRS employees were interviewed for this documentation and each provided a tremendous amount of information about the history of 777-M's operations. Full transcriptions of the personal interviews are provided in the Field Records.

Baumann, Dr. Norman P., Aiken, SC; tour of Building No. 777-10A, October 1998; personal interview, October 1999 (now deceased).

Brecht, John, SRS Photography and Video Documentation Services; telephone interview, July 2006.

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Kotti, Tom, SRS Photography and Video Documentation Services, telephone interview, July 2006.

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E. Likely Sources Not Yet Investigated:

The author has tried to be as comprehensive as possible but there are always additional avenues of research. Some information concerning 777-M's operational life may be held within classified records. Archival collections at Argonne National Laboratory may also yield data on early reactor types that was unavailable to this study.

PART IV. PROJECT INFORMATION

The Physics Assembly Laboratory or 777-M was determined eligible to the National Register of Historic Places (NRHP) by the DOE and South Carolina State Historic Preservation Office (SHPO) in 2003 at the national level for its significance in engineering and its association with the Cold War. It was also considered to be eligible as part of a SRS Cold War Historic District. DOE stewards its NRHP-eligible properties under a Programmatic Agreement that stipulated the creation of a Cultural Resources Management Plan (CRMP). This HAER Level II documentation was performed as mitigation for the loss of the historic property demolished in 2005. SHPO concurred with this mitigation approach in 2004 through a formal notification process defined in the CRMP for SRS undertakings that affect SRS Cold War properties.

Washington Savannah River Company (WSRC) and New South Associates conducted the HAER study between 2004 and 2006. Byron Williams and Steven Ashe with WSRC were project photographers. It should be noted that due to the presence of radiological contamination and other safety constraints, medium-format photography was used to document areas in the building including the SP/SE Reactor Room on –15 level where large-format photography was not permitted. The medium-format views have been submitted as field records with an index as advised by the National Park Service. Historic views from the 1960s of this important area were included in Appendix A to balance out this omission in the large format photographic documentation. In addition, medium format detail views of the PDP's sheave racks, motors, tilting table and an aerial view of the PDP tank top are included in the field records.

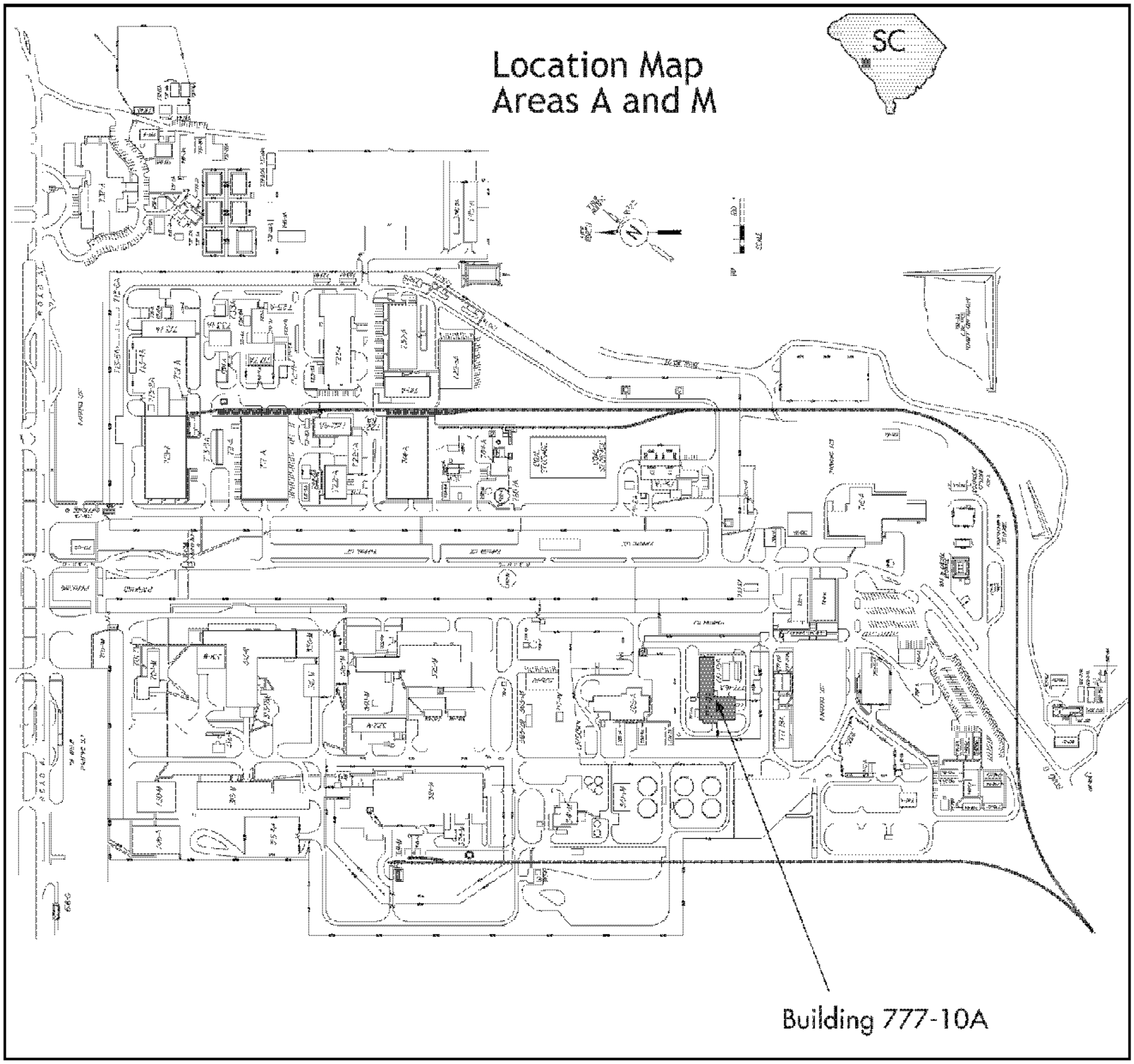
Mark Swanson of New South Associates was the project historian and he performed the research, conducted the oral interviews, and compiled the documentation. Mary Beth Reed, also with New South Associates, assisted with the photographic fieldwork and project oversight.

Dr. Norman Baumann, Dr. Peter Gray, Mr. Tom Gorrell were interviewed for this documentation and each need to be acknowledged for their rich contributions. The transcriptions of these interviews are provided in the field records with this project. Mr. Chuck Jewell also contributed to the historical research, helping with the identification of historic photography. Mr. Fred Rhode and Mr. Tom Kotti were other knowledgeable informants who gave of their time to answer questions during the study.

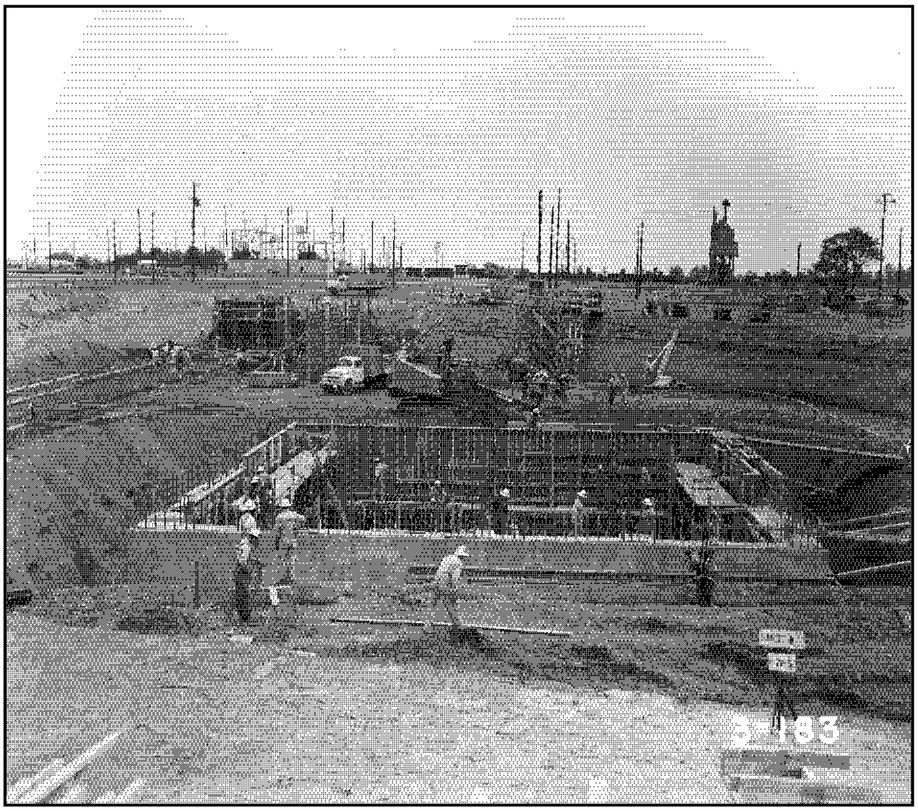
Others were also instrumental in the project development and completion. They are: Mr. Dennis Godsbee, Mr. John Knox, and Mr. Nick Delaplane with the Department of Energy; Mr. Thomas Feske, Ms. Linda Perry, Dr. Christopher Noah, and Mr. Joe Carter with Washington Savannah River Company (formerly Westinghouse Savannah River Company); and Mr. Randall Walker with CM2MHill. Ms. Mary Edmonds and Mr. John Sylvest at the South Carolina State Historic Preservation Office provided direction and support. Finally, stakeholders and retirees, Mr. J. Walter Joseph and Dr. Todd Crawford, helped frame the project, suggested individuals for oral history interviews and provided inspiration.

Even though 777-M is now demolished, various aspects of the structure were preserved before the 2005 demolition. Much of the equipment in the PDP control room was preserved, including the console desk and all of the control panels. The PDP tank top, including cover plates and beams, was also saved. Out of the material associated with the SP-SE, the General Electric console desk was saved from the SP-SE control room, as were the adjacent control panels. These various items were conserved as part of the preservation program at the Savannah River Site, a program dedicated to the achievements made by those who worked at Savannah River over the past fifty years.

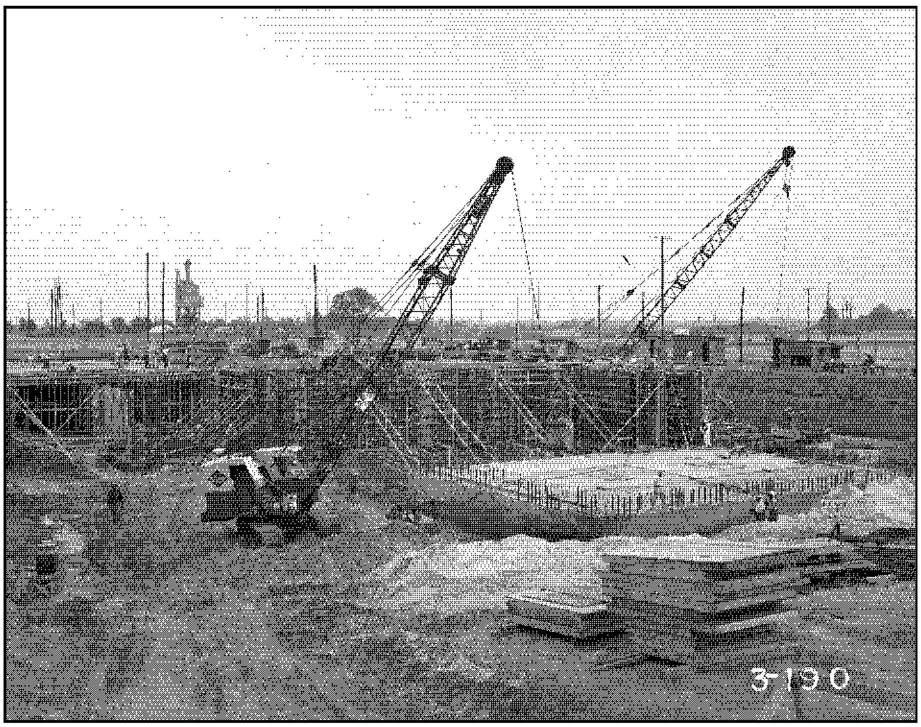
APPENDIX A — LOCATION MAP, HISTORICAL VIEWS AND DIAGRAMS



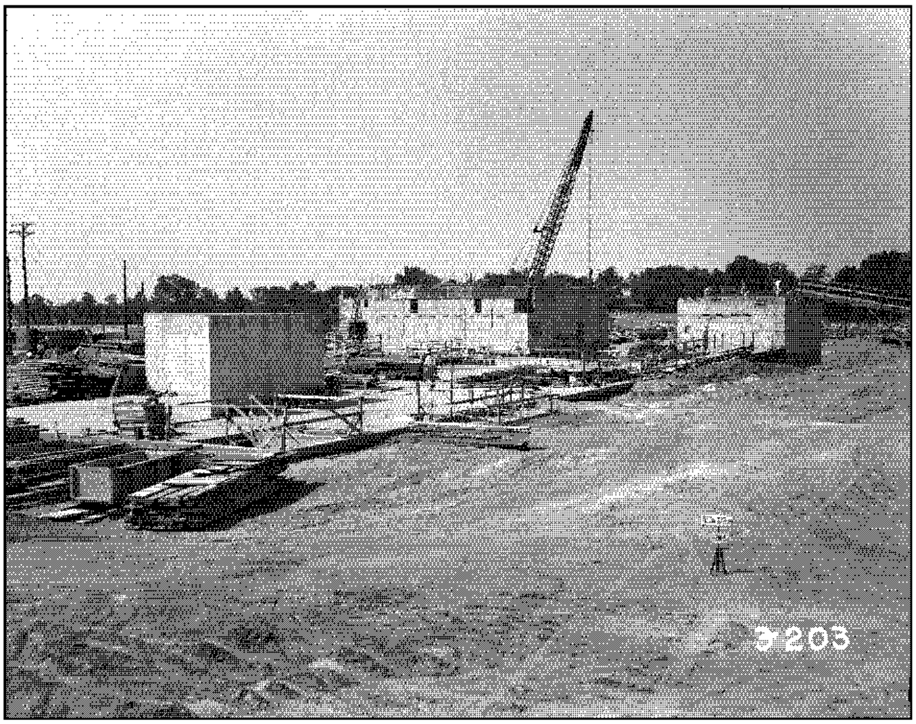
Location Map Showing Location of Physics Assembly Laboratory, shown as 777-10A, at SRS in 2000 within the Lower 700 Area.



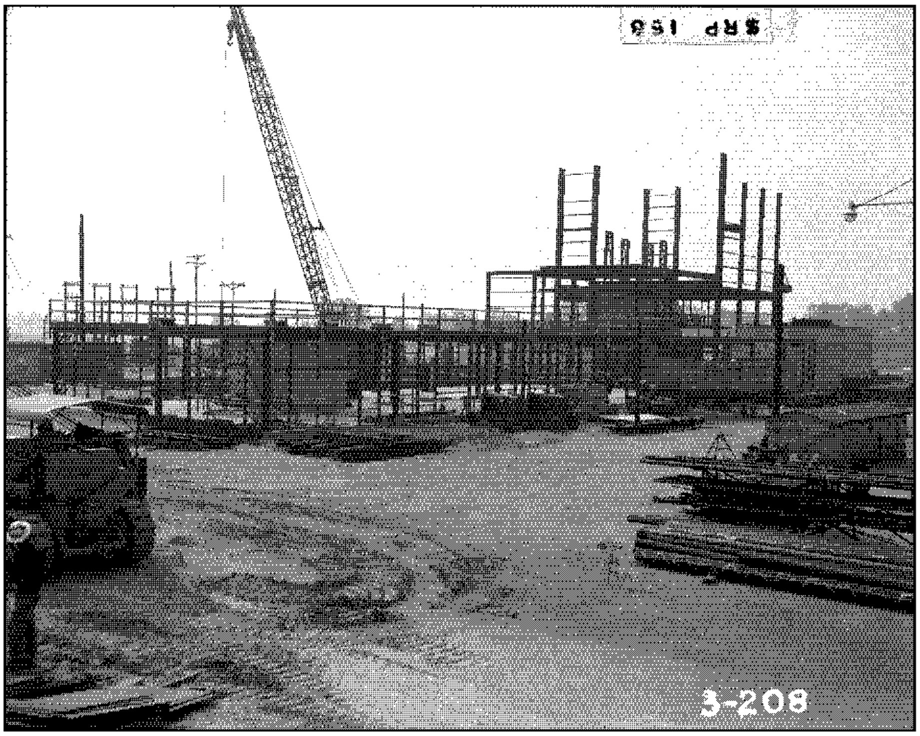
View of Construction of Reactor Wing Below Grade Showing Depth of Excavation, Pouring of Concrete and Use of Reinforcement Bar, Building 751-1A Appears in Background, View to the East, April 29, 1952.
(SRS Negative No. 3-183)



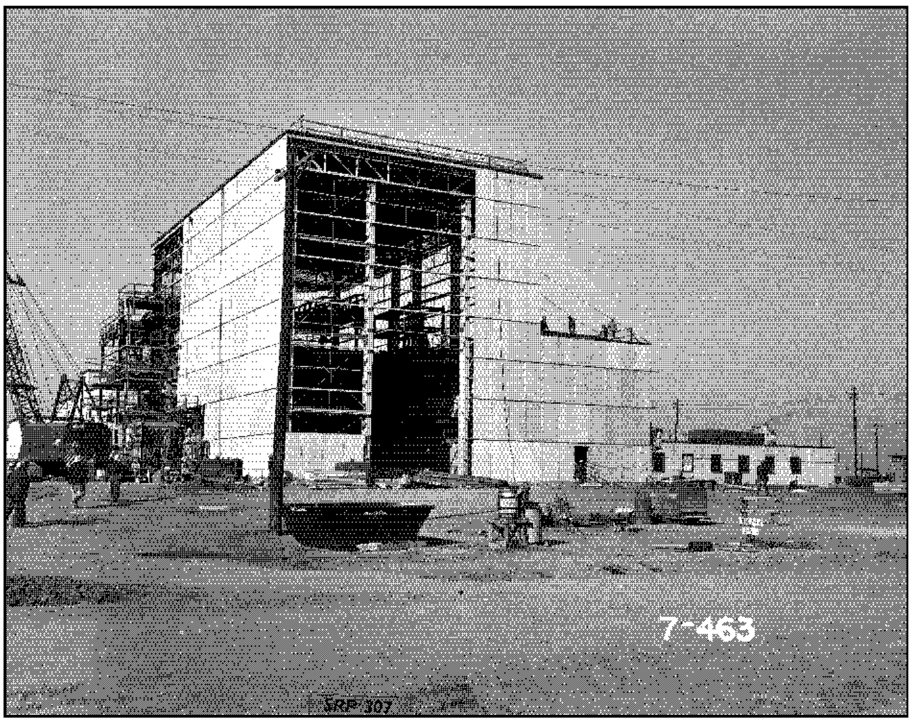
View of Below Grade Construction of Reactor Wing With Concrete Forms in Place, July 28, 1952.
(SRS Negative No.3-190)



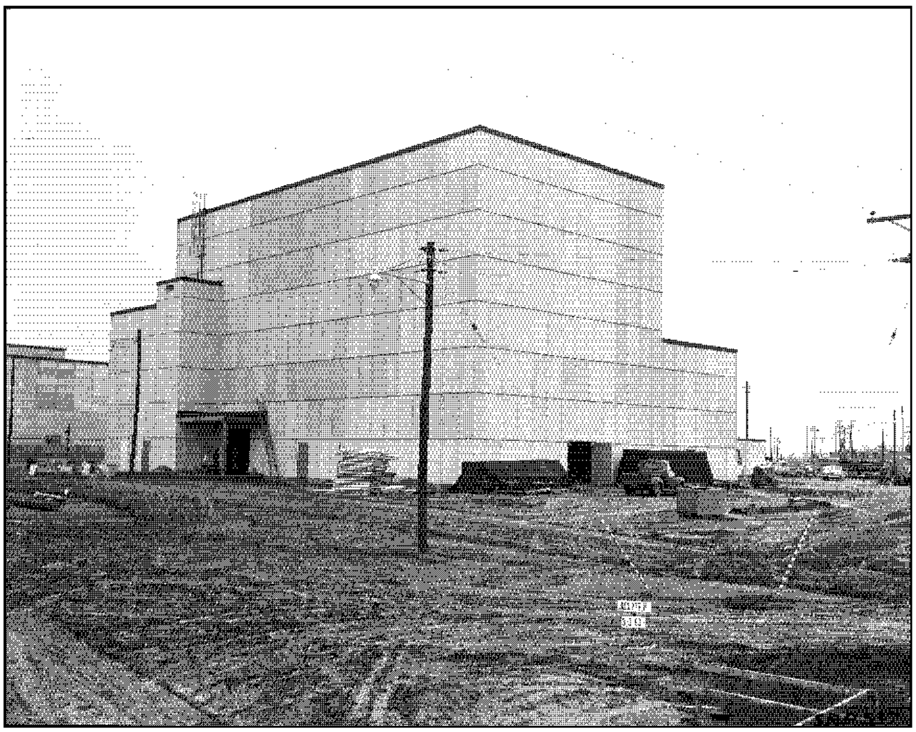
View Showing Concrete Construction in Reactor Wing, September 28, 1952. (SRS Negative No. 3-203)



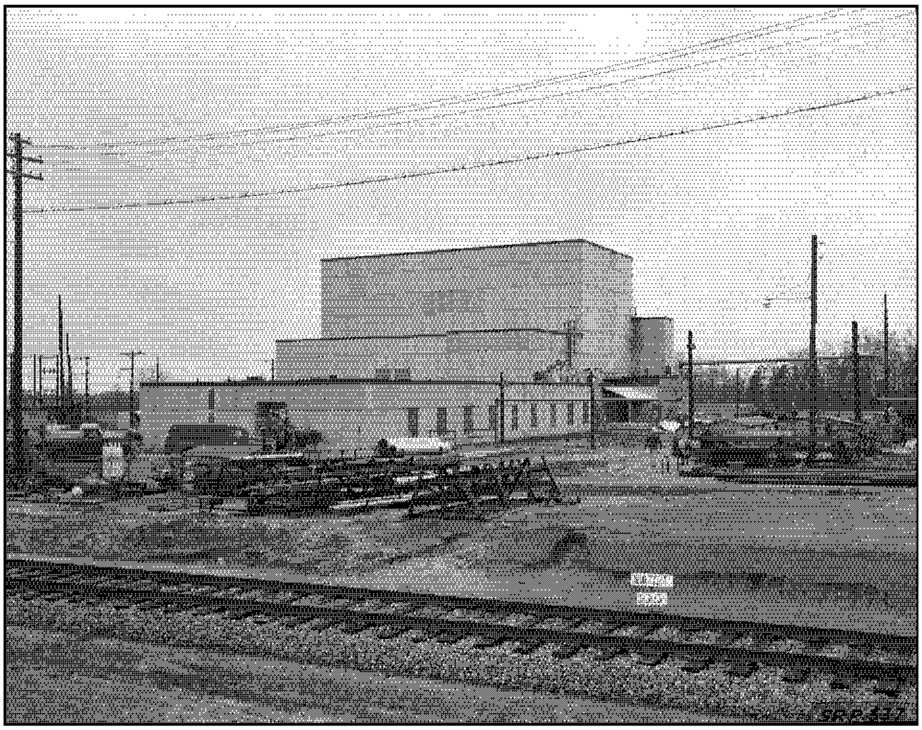
View Showing Steel Framing for Building, Laboratory Wing in Foreground, View to the Southeast, December 29, 1952.
(SRS Negative No. 3-208)



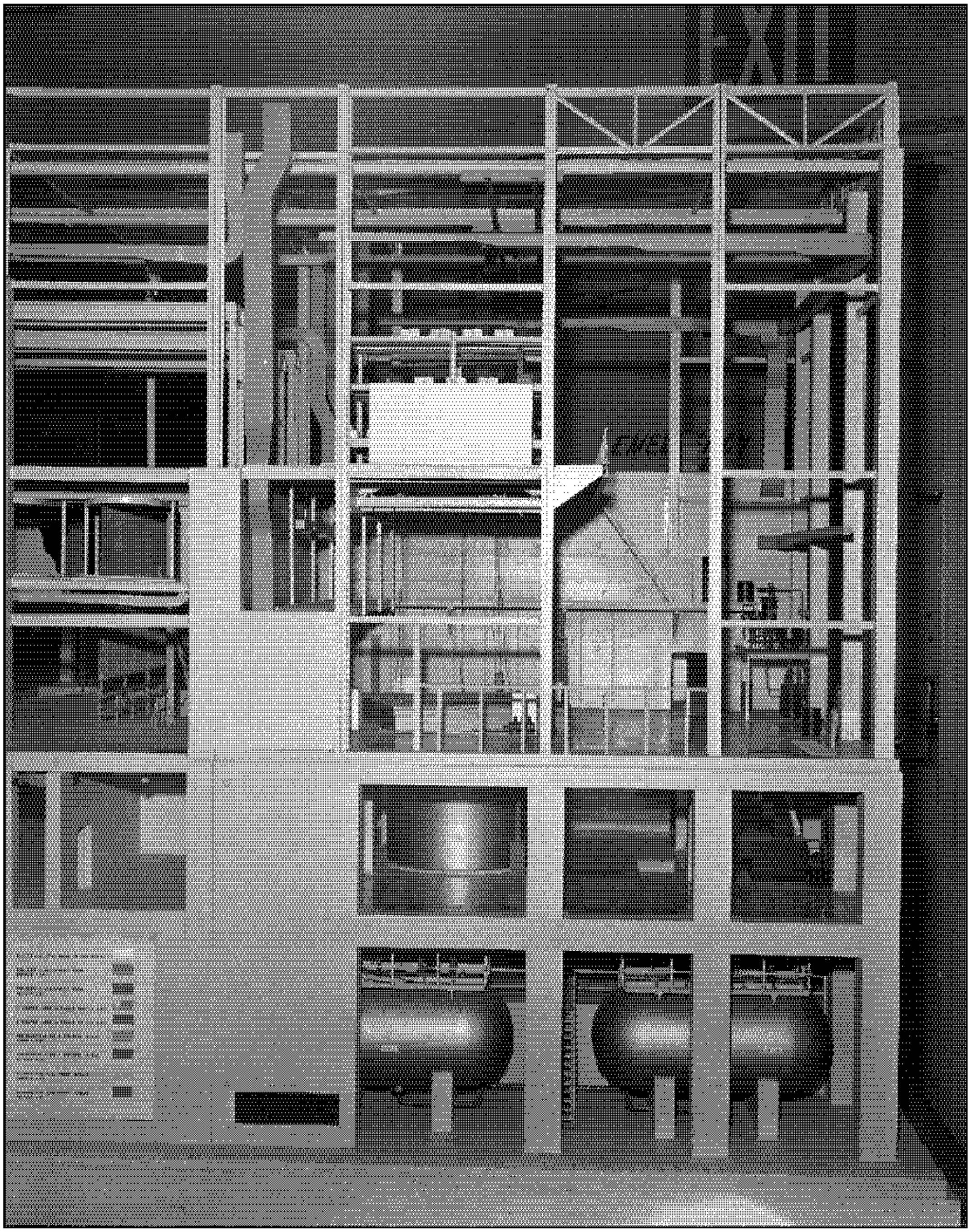
View Showing Steel Frame Construction in Reactor Wing and Future Opening for Large Overhead Door on South Side, View to the Northeast, December 29, 1952.
(SRS Negative No. 7-463)



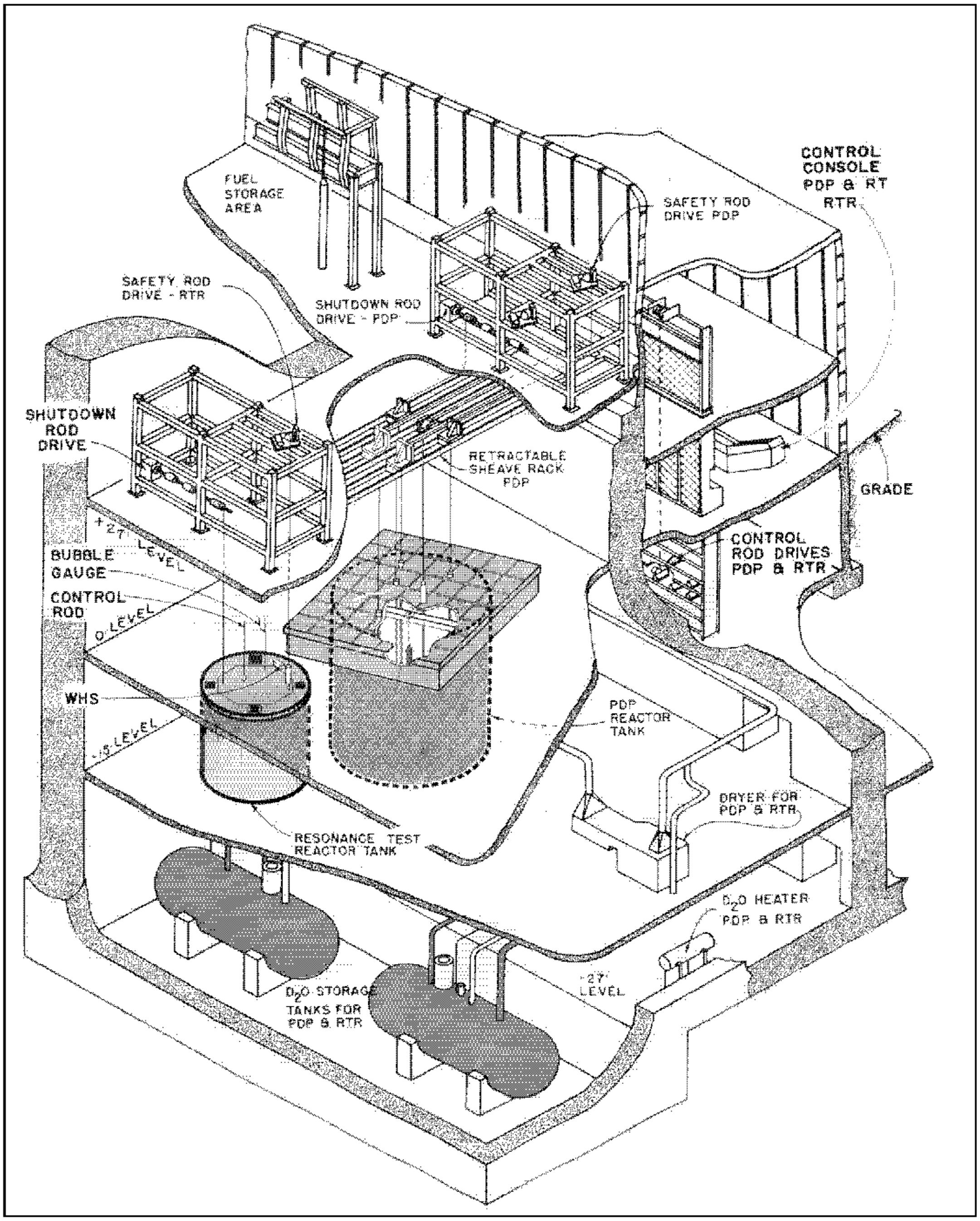
Rear View of Reactor Wing, View to the Northeast, October 2, 1953. (SRS Negative No. 7-506-1)



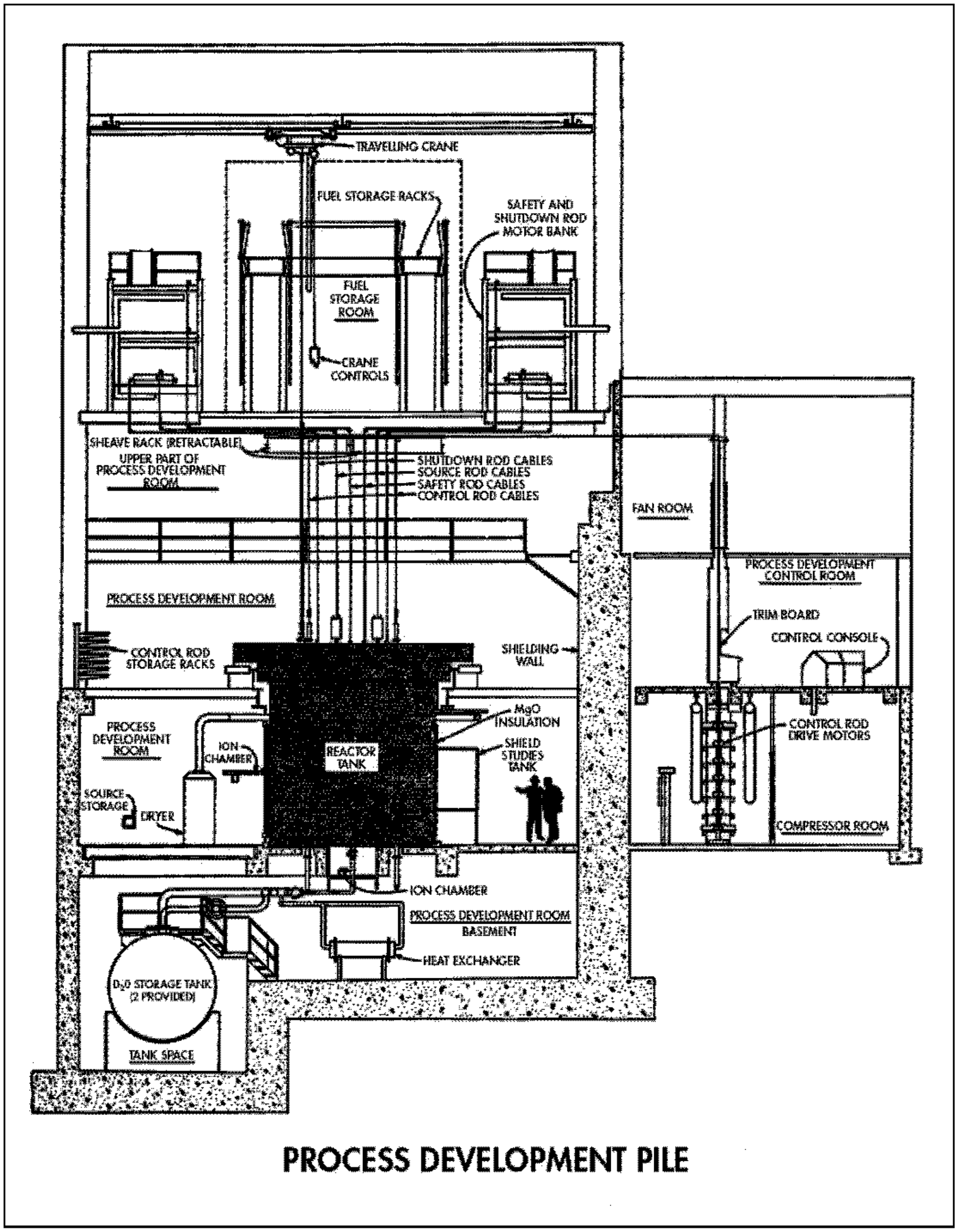
View of Laboratory Wing in Foreground After Completion, Multistory Reactor Wing in Back, View to the Southwest, December 15, 1952. (SRS Negative No. 7-506-2)



Partial View, Du Pont Building Model for 777-M that Shows the Multilevel PDP Area in Reactor Wing. See Following Isometric Drawing for Level Identification. (SRS Negative No. DPSTF-1-2379)



Isometric Drawing Showing the Functional Relationship between the Equipment in the PDP Process Area, Date Unknown.



Isometric Drawing Showing the Component Parts of the PDP and their Spatial Relationships. Source: SRS Curation Facility

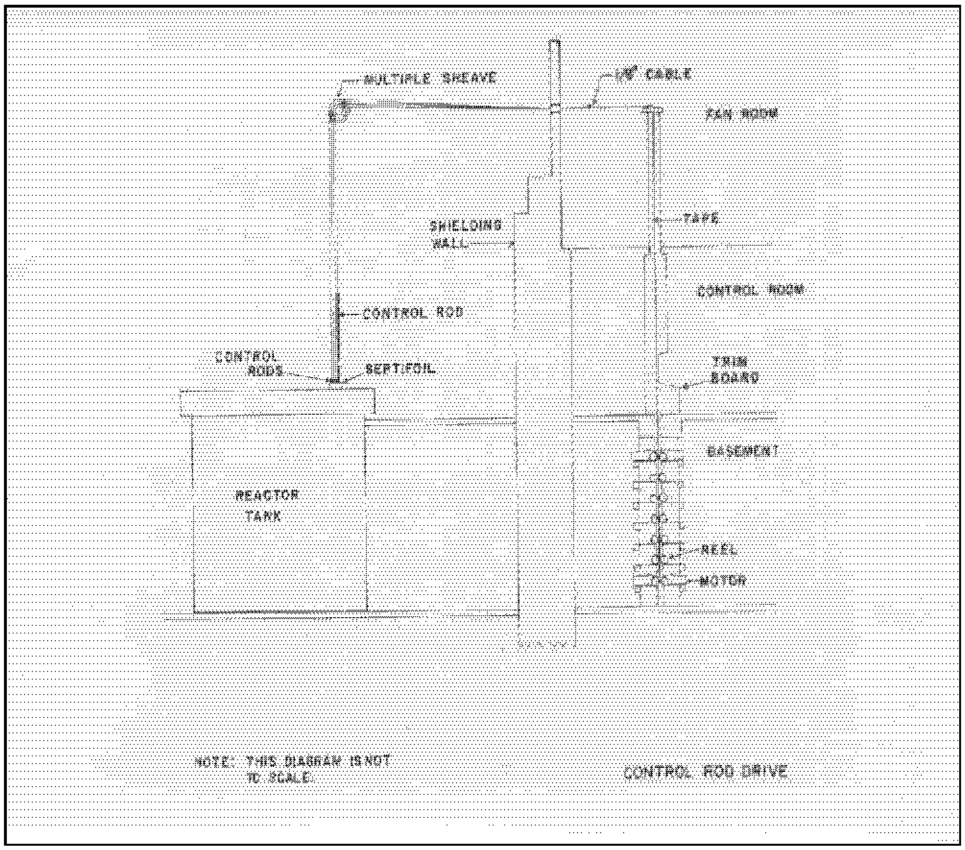
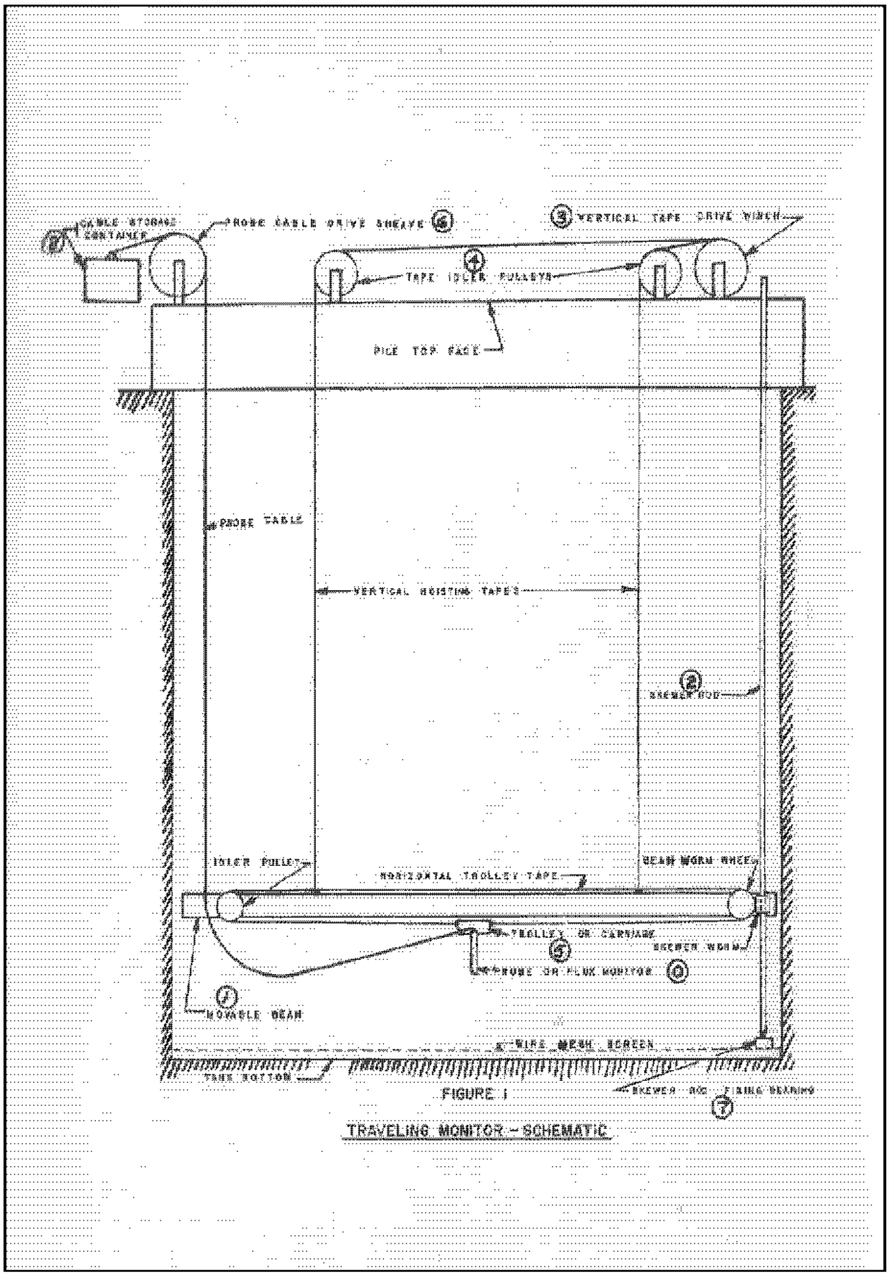
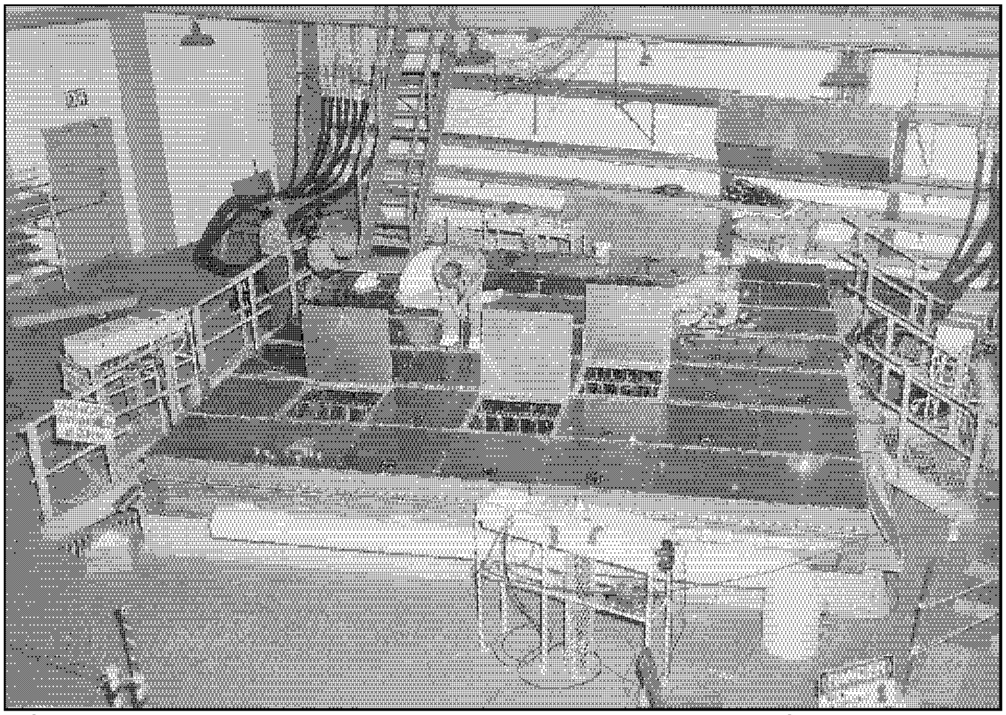


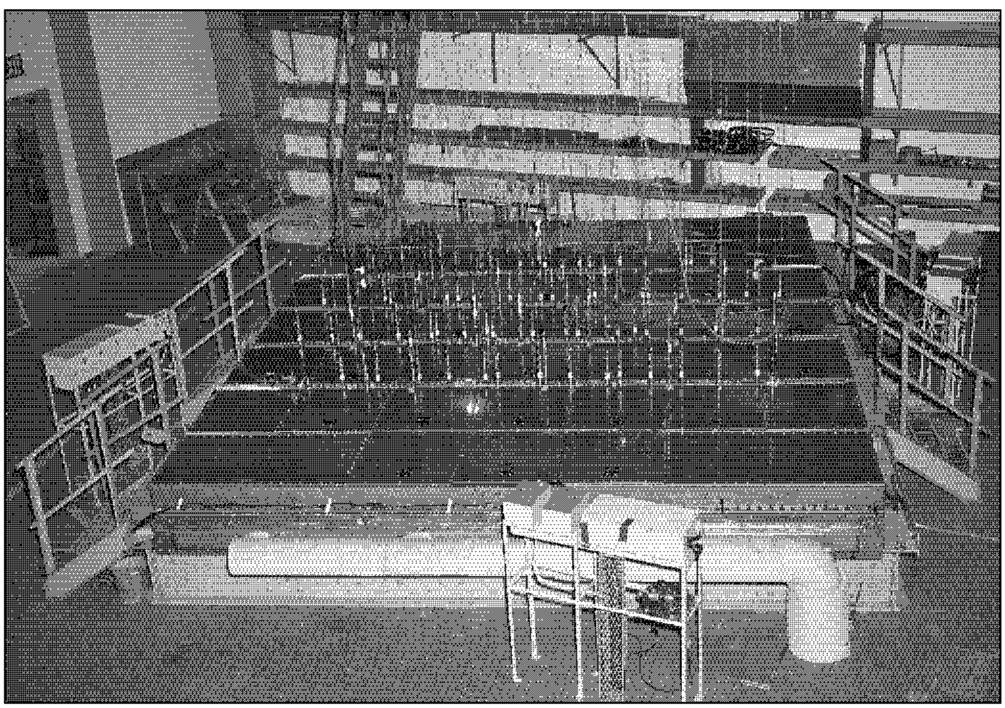
Diagram of Control Road Drive (A Motors) for the PDP, Showing Reactor Tank and Location of Trim Board in PDP Control Room, ca. 1960. (SRS Negative No. DPSTF-1-85)



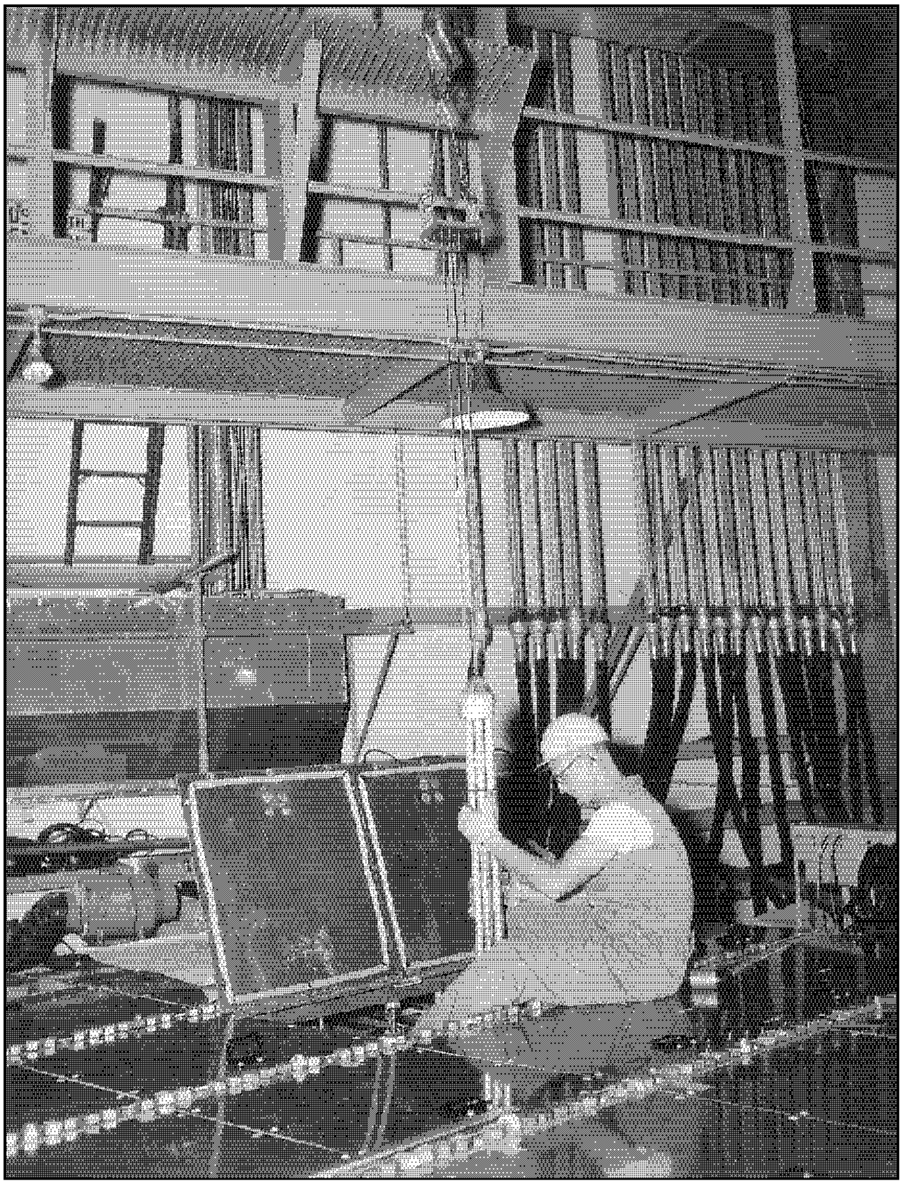
Schematic Drawing of Traveling Flux Monitor In PDP.
(SRS Negative No. DPSTF-1-127)



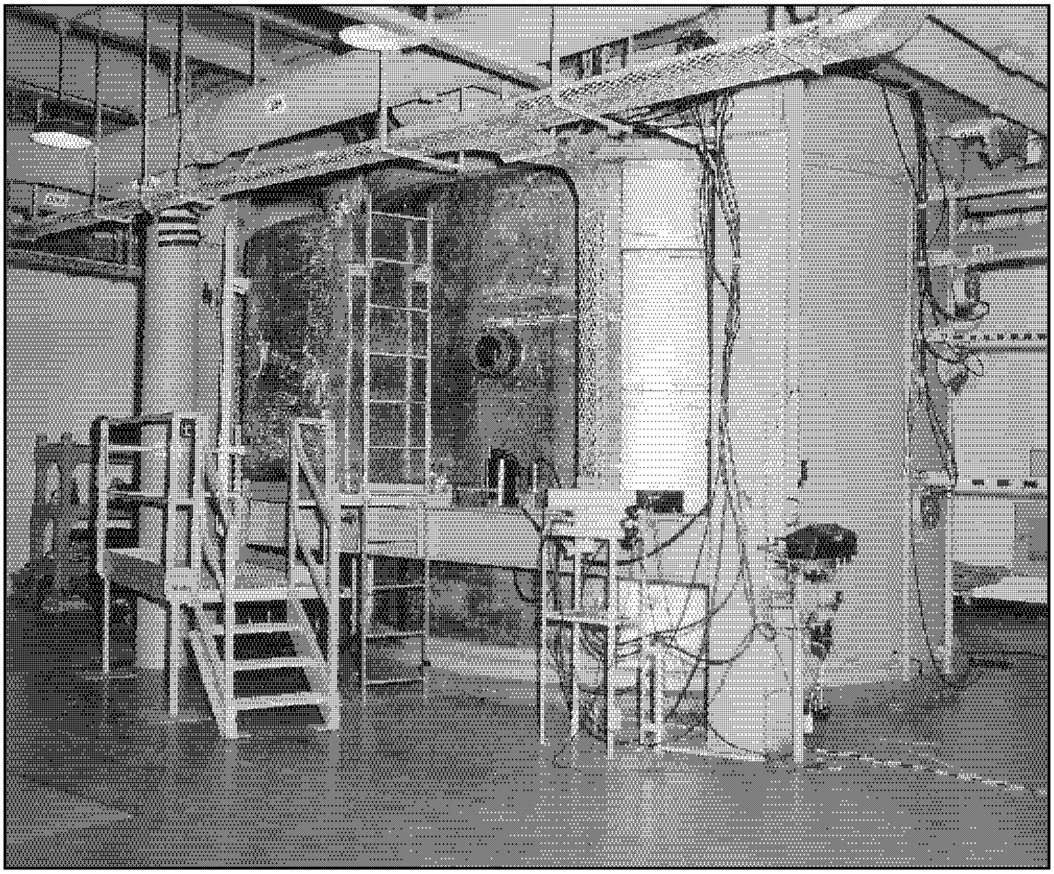
View of PDP Tank Top Cover Plates Under Construction, late 1950s. (SRS Negative No. DPSTF-1-2536)



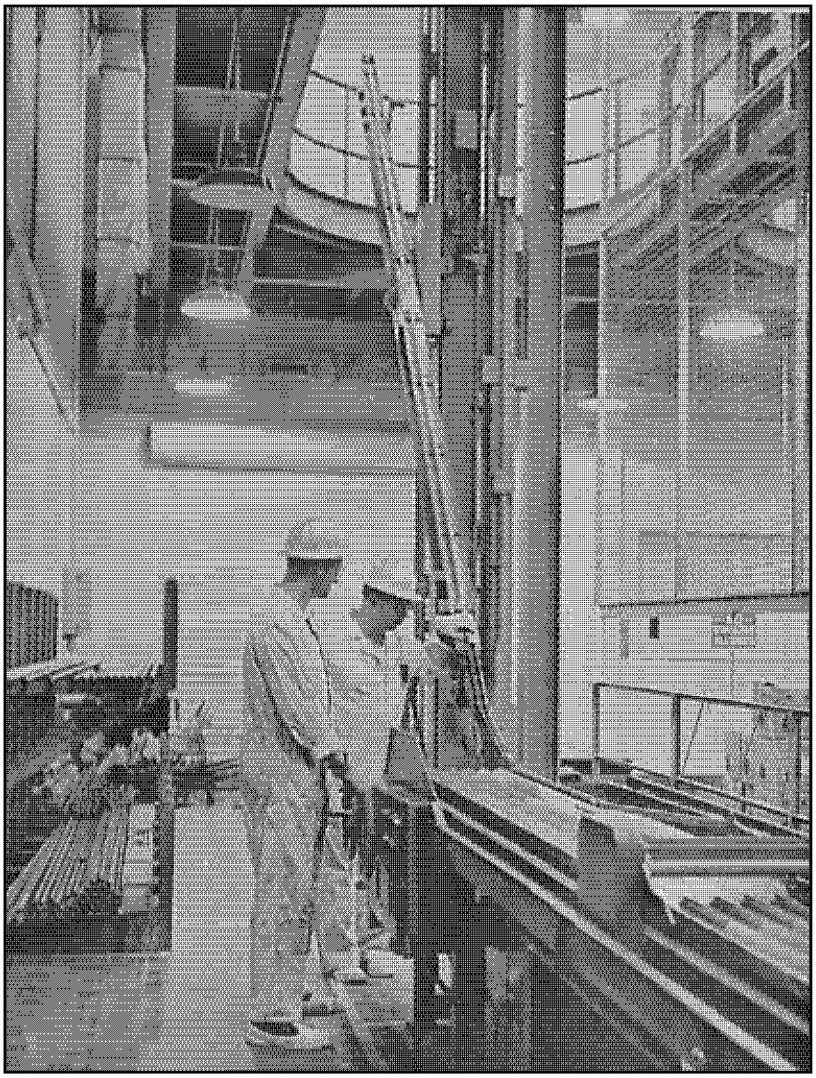
View of PDP with Completed Tank Top and Cables, late 1950s. (SRS Negative No. DPSTF-1-2610)



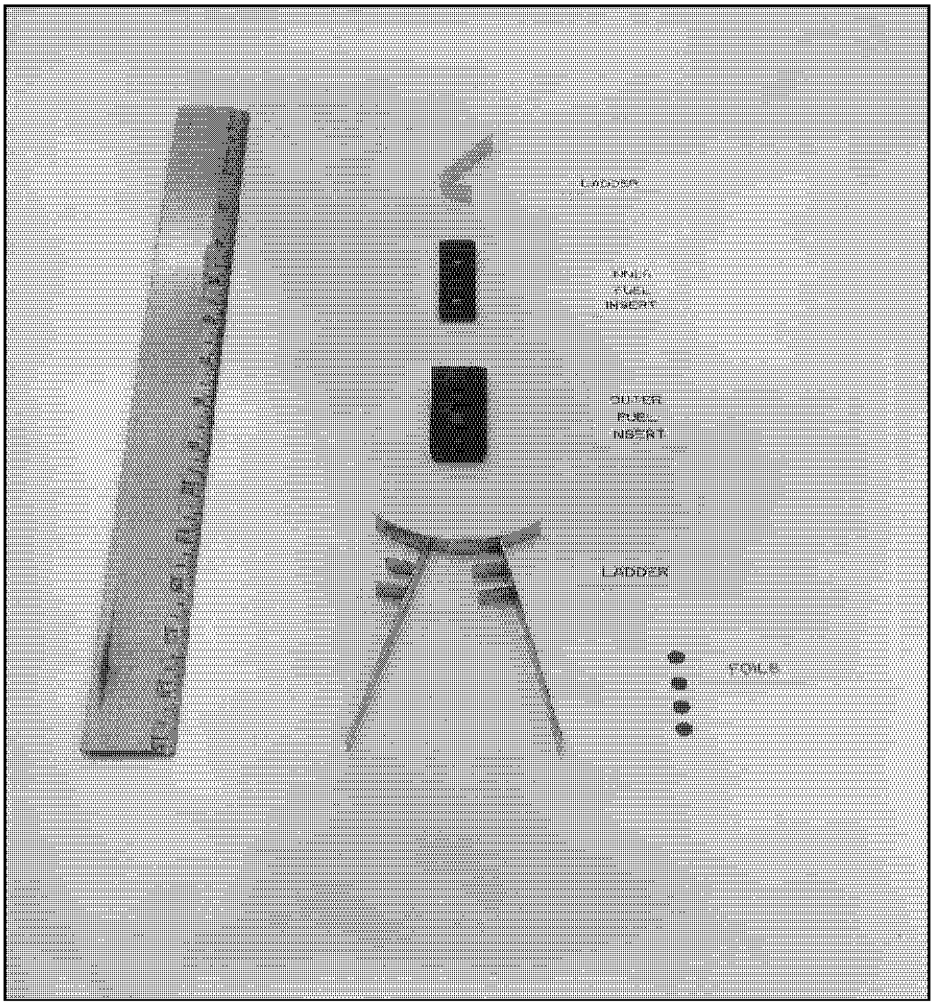
John Kennedy Making Adjustments to PDP, ca. 1958. (SRS Negative No. DPSTF-1-2561)



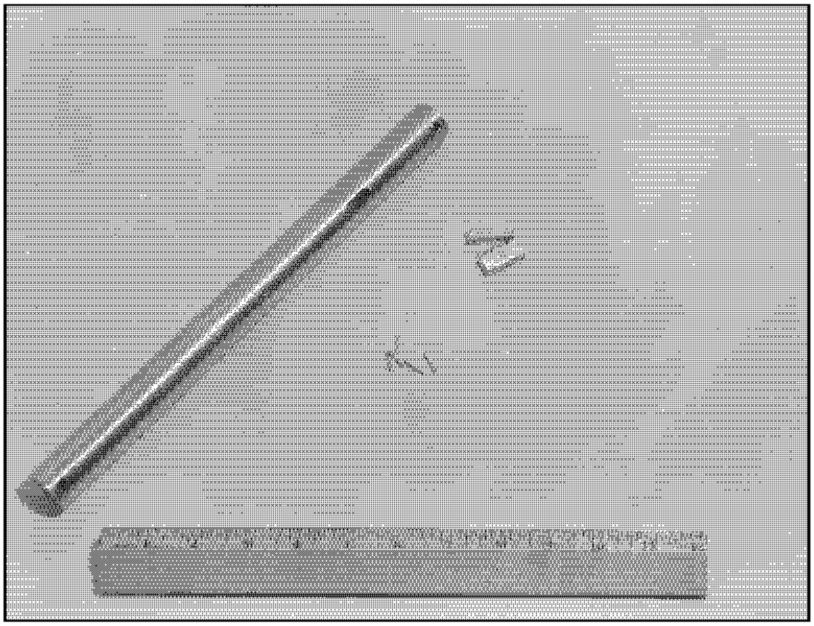
View of PDP Tank, -15′ level showing small ion chambers on side of tank, ca. 1960. (SRS Negative No. DPSTF-1-2386)



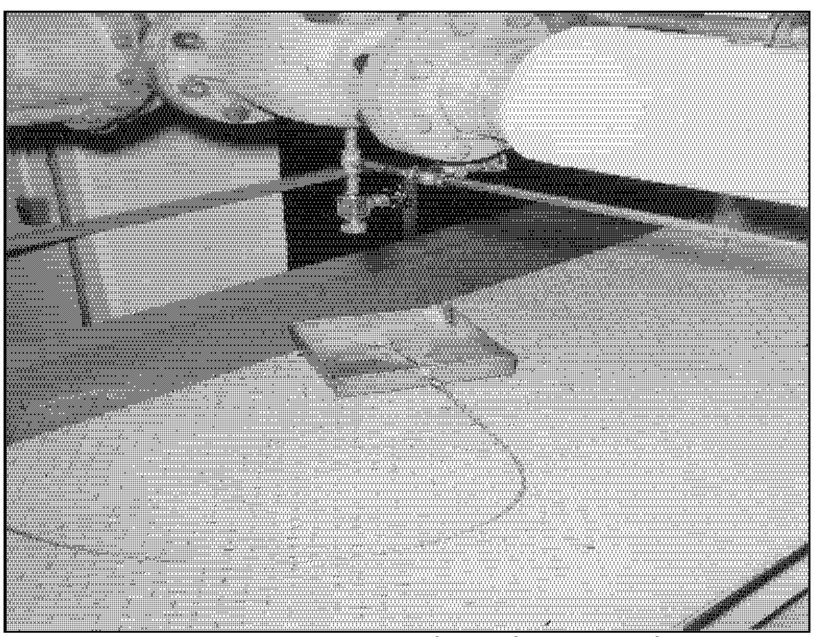
Two Operators, John Kennedy and Bob Kneece, Working With Tilting Table, +27 Level, ca. 1960.
(SRS Negative No. DPSTF 1-94)



View of PDP Ladders, Foils, and Fuel Inserts, ca. 1960.
(SRS Negative No. DPSTF-1-2663)



View of Gold Pins (five small pins in center) and Cases to be Irradiated, ca. 1960s.
(SRS Negative No. DPSTF-1-166)

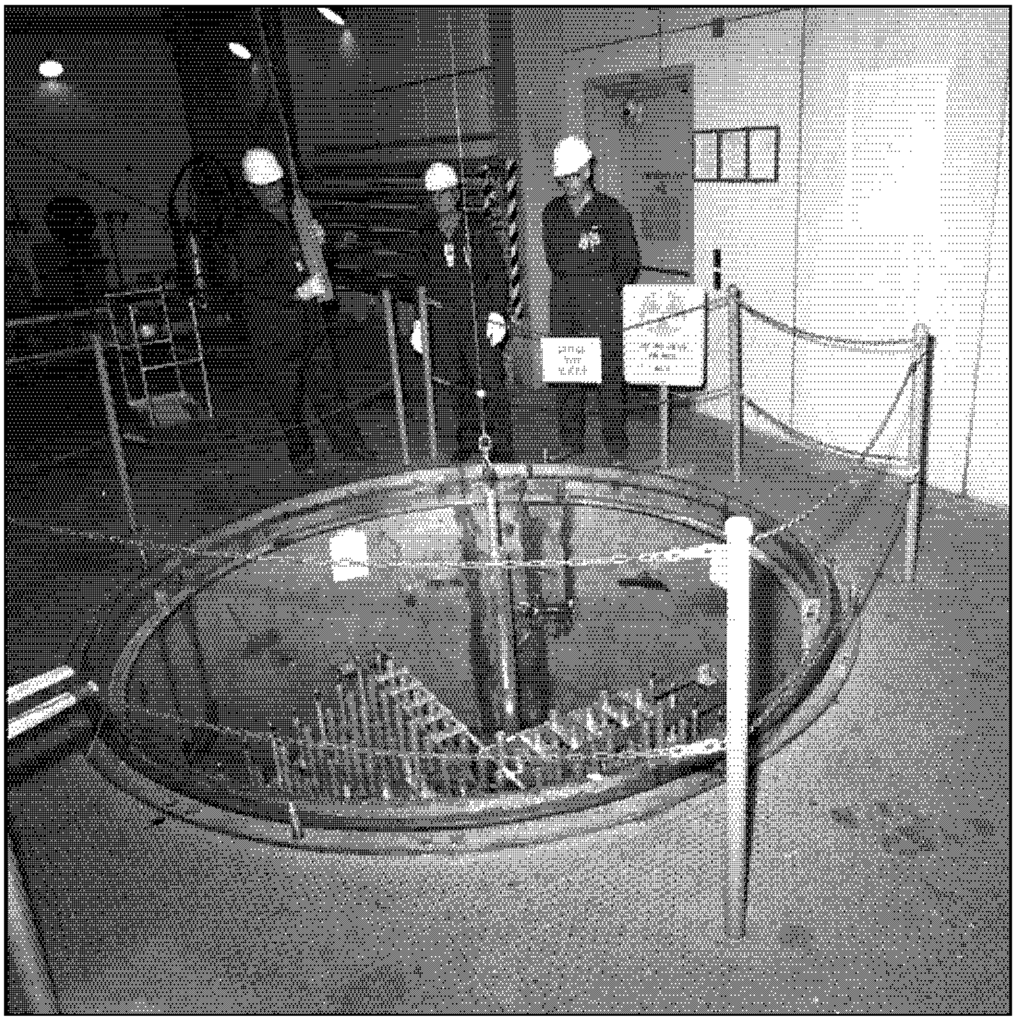


"Beetle" (Rectangular Pan with Wire)- Device Used to Detect Presence of Heavy Water Leak in PDP Room, ca. 1960. (SRS Negative No. DPSTF-1-3711)

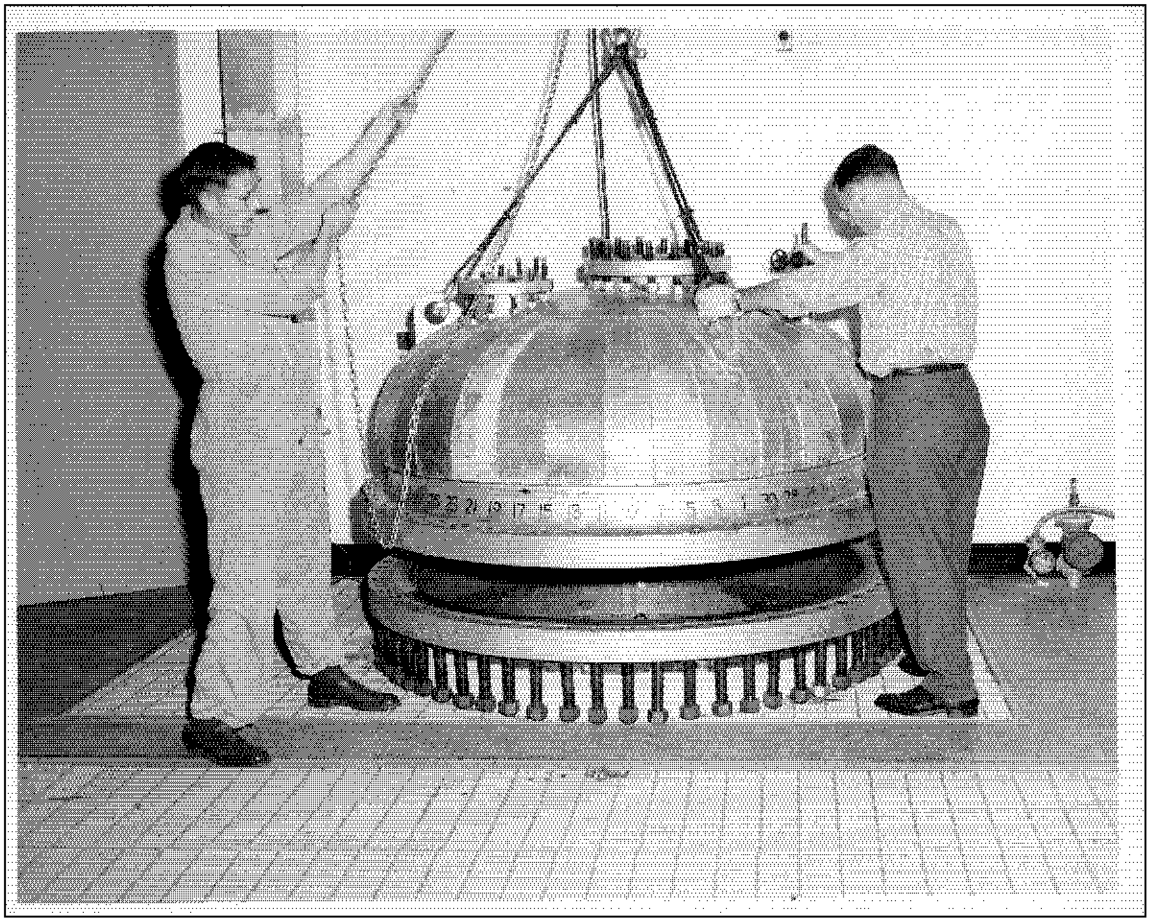
PDP Control Room, 0' Level, Trim Board on Left, Console to the Right, Desks in Foreground. Office/Laboratory at Rear with Partial Glass Walls, 777-M Building Model behind Console. (SRS Negative No. DPSTF-1-2378)

Detail of Console with Operator, Barney Finn, and Workers, late 1950s.
(SRS Negative No. 3360-58)

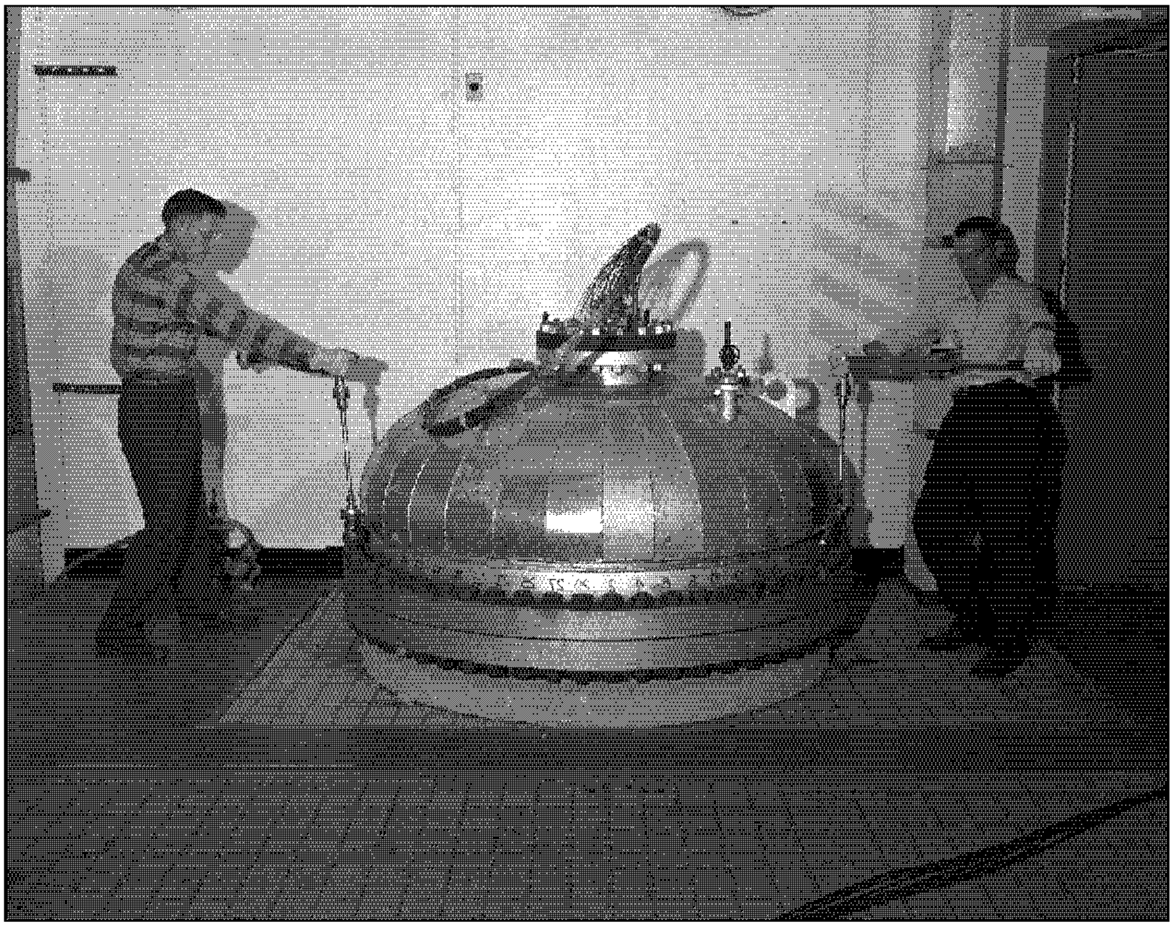
PDP Control Room, O' Level, Console on Left and Trim Board on Right. "A" Motor Tapes, Suspended in Groups, Are Visible Between Top of Trim Board and its Lower Cabinet, ca. 1965. (SRS Negative No. DPSTF-1-2377)



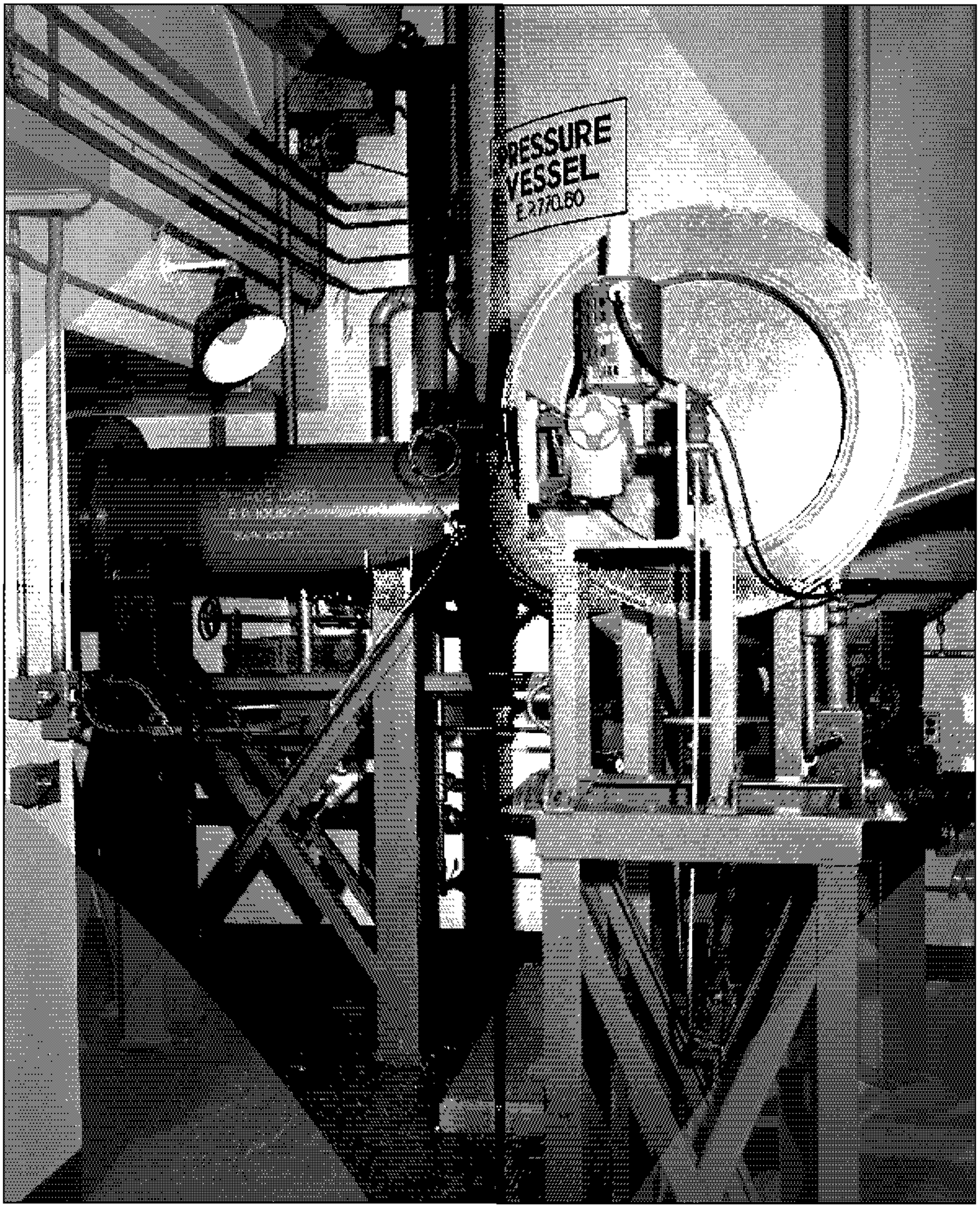
Lattice Test Reactor, Known Earlier as Resonance Test Reactor,
with Operators Loading Reactor, 0' Level, undated.
(SRS Negative No. 1-13936-2)



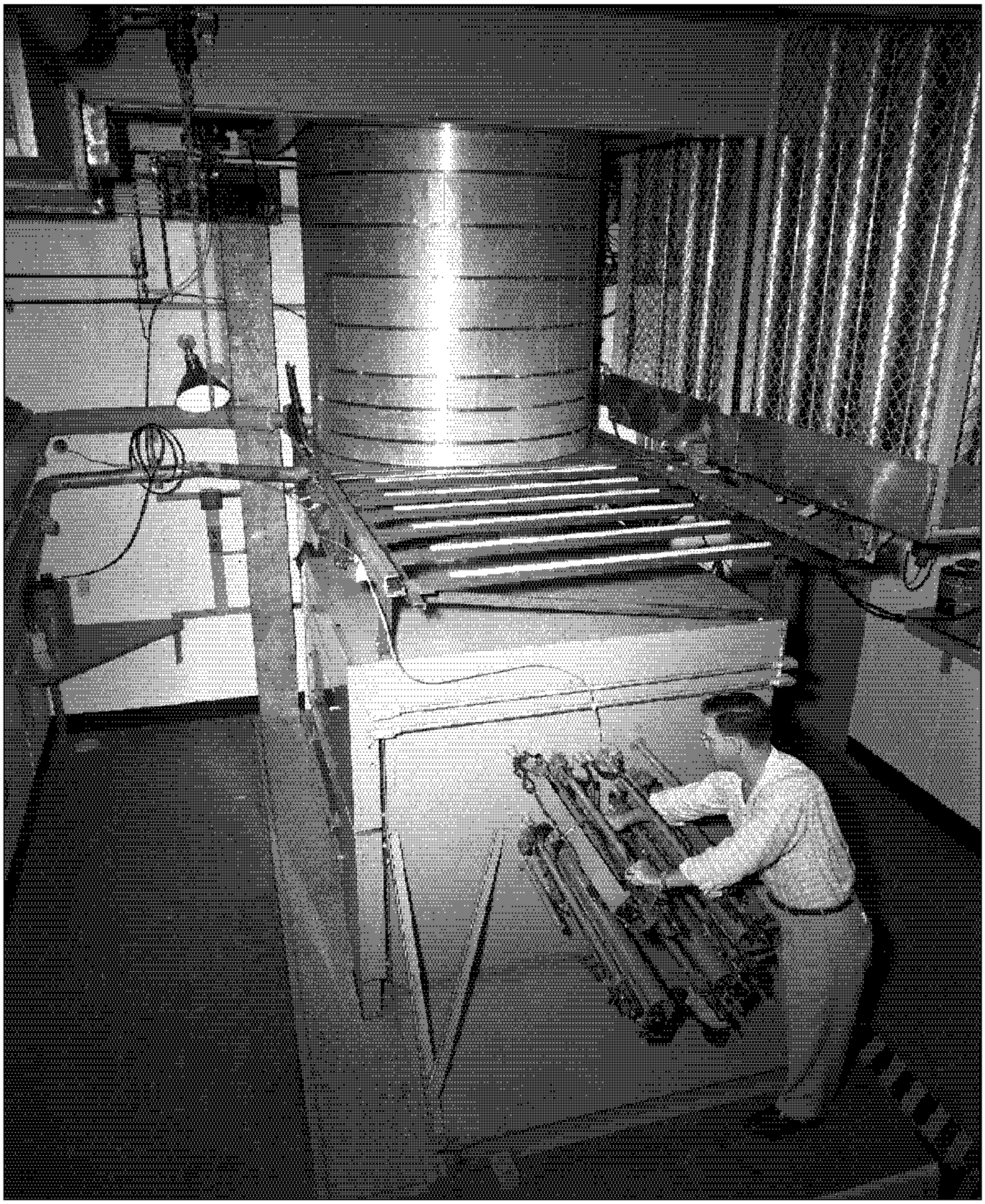
View of PSE Tank Top Lowered into Place by John Price (left) and Sam Burdette, 0' Level, ca. 1960. (SRS Negative No. not known)



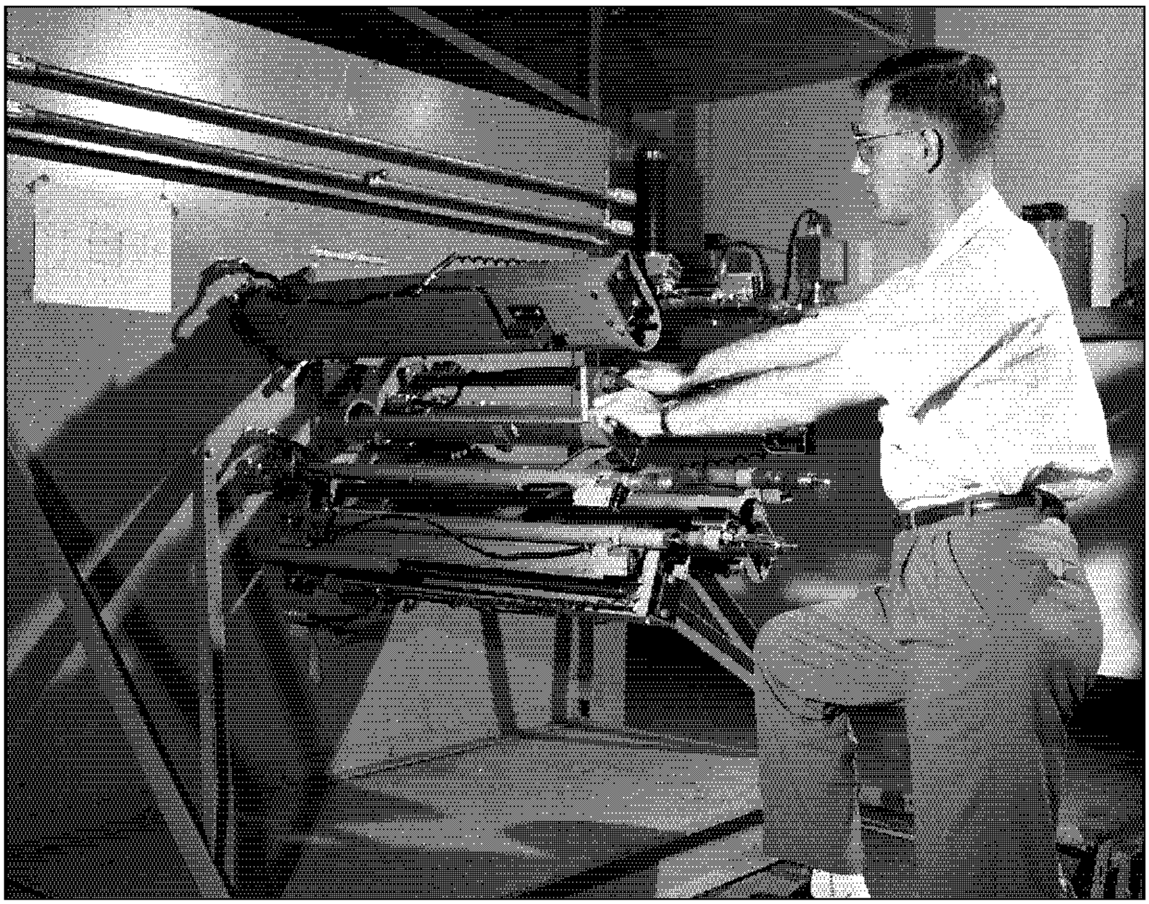
View of Measurements Being Taken from PSE by John Price (left) and Sam Burdette, 0' Level ca. 1960. (SRS Negative No. DPSTF 1-2631)



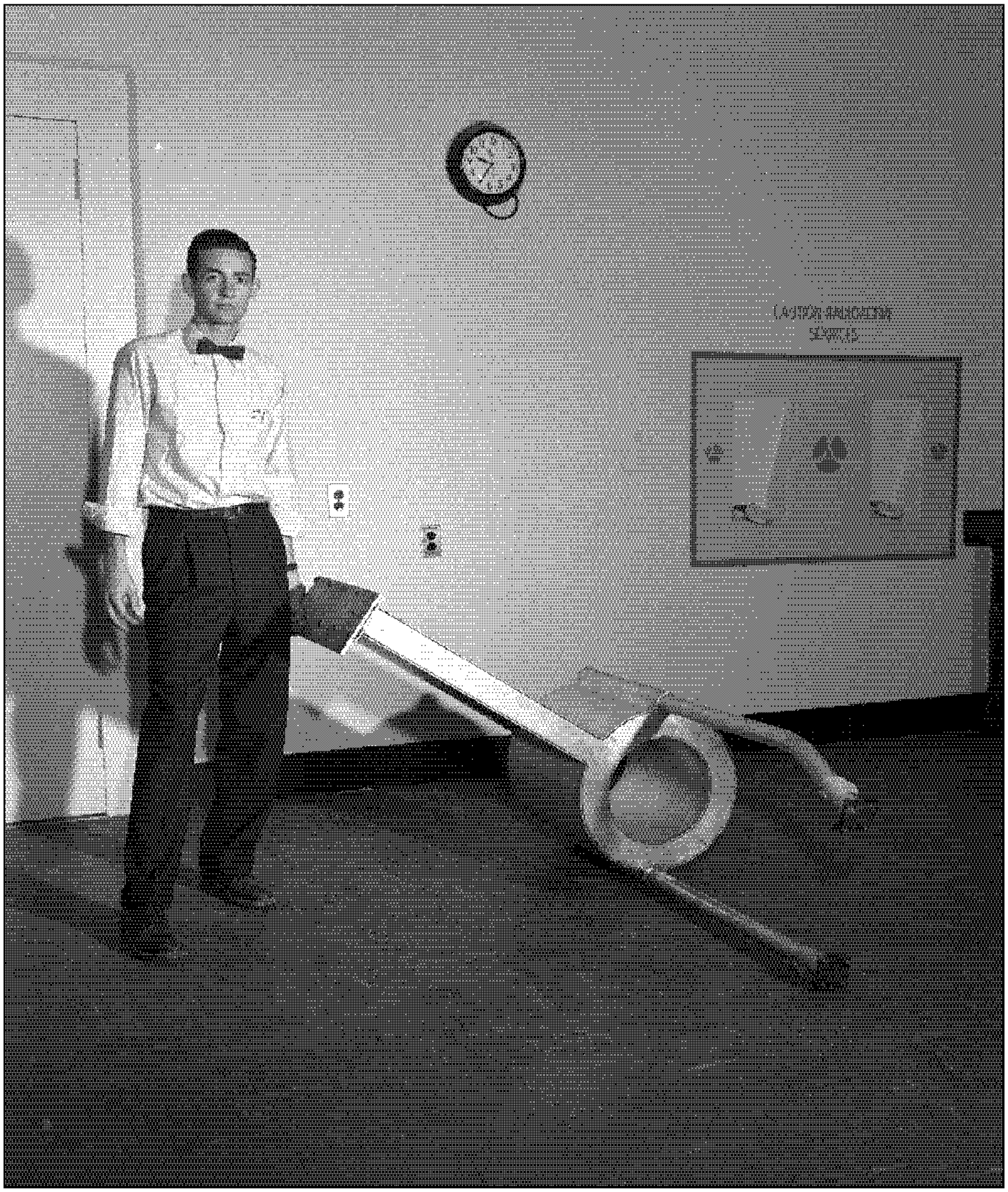
PSE Test Reactor Vessel, -15' Level, ca. 1960. (SRS Negative No. DPSTF 1-2634)



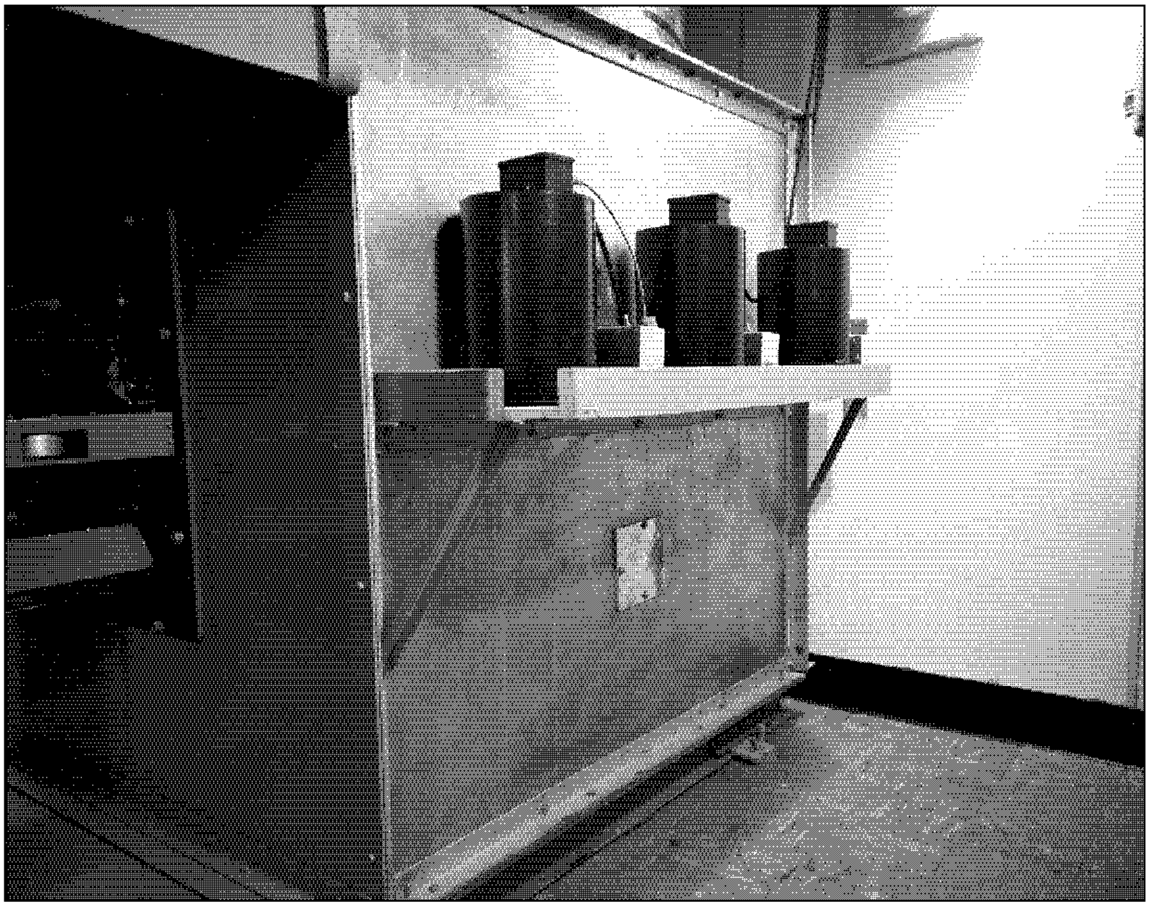
Engineer Sam Burdette at Face of SP Reactor, -15' Level, ca. 1960.
(SRS Negative No. 3360-2-56)



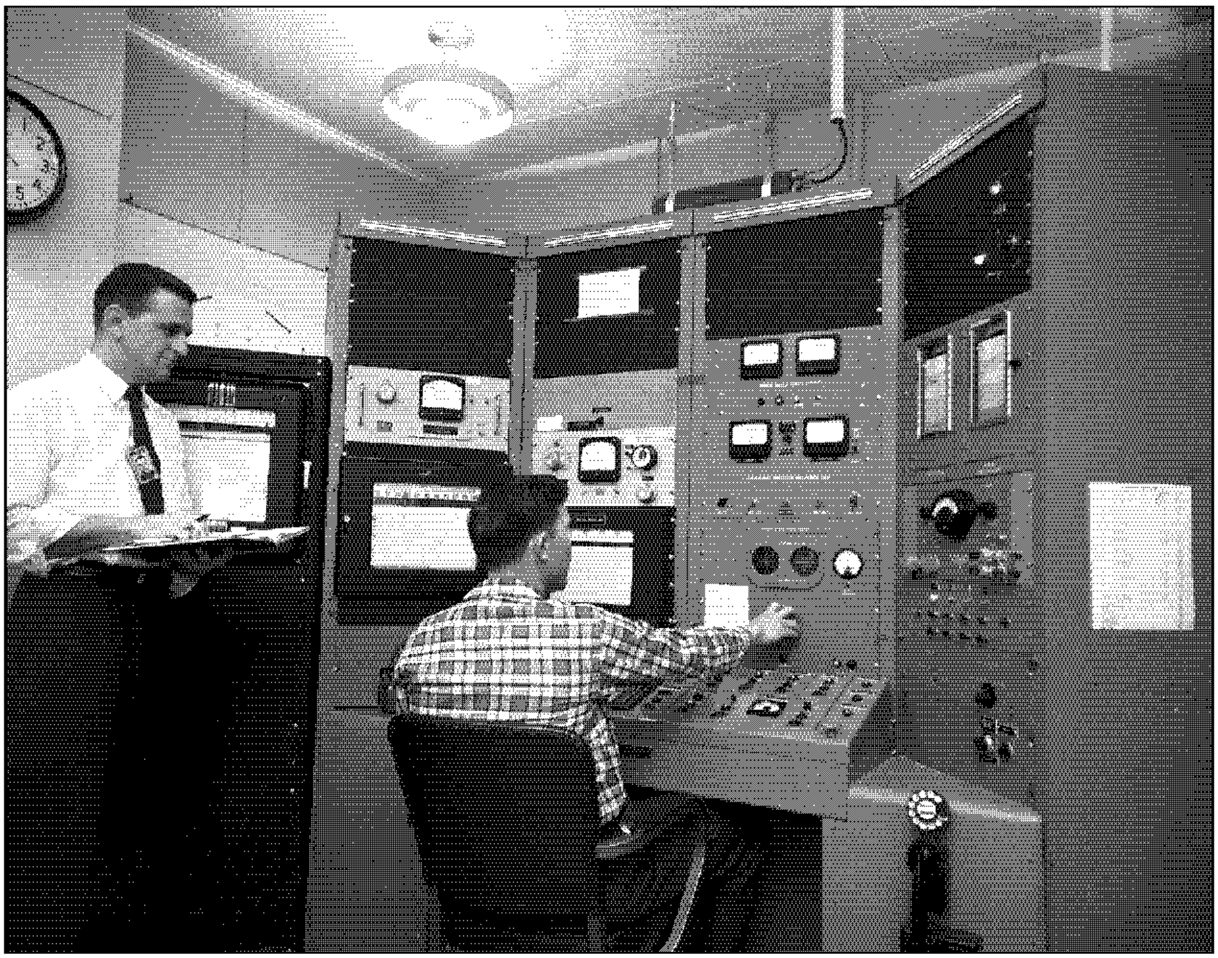
Oblique View Showing SP Test Reactor Face with Engineer Sam Burdette Making Adjustments, -15' Level, ca. 1960. (SRS Negative No.E-4427-11)



Bow-Tied Operations Employee Jim Wade with Interior Core of SP Test Reactor; Wall containers for safe disposal of contaminated source rods on back wall, -15′ level, ca. 1953. (SRS Negative No. 1023-3)



Side View of SP Reactor Showing Ion Chambers. (SRS Negative No.1023-7)



Control Room Console for SP/SE Test Reactor, 0' Level, ca. 1960. Scientist Tom Gorrell on left, John Price at console. (SRS Negative No. 3360-2-60)

APPENDIX B — GLOSSARY OF NUCLEAR TERMS

Alpha particle
A positively-charged particle from the nucleus of an atom, emitted during radioactive decay.

Atom
A particle of matter which cannot be broken up by chemical means. Atoms have a nucleus consisting of positively-charged protons and uncharged neutrons of the same mass. The positive charges on the protons are balanced by a number of negatively-charged electrons in motion around the nucleus.

Atomic Bomb
An explosive device whose energy comes from the fission of heavy elements such as uranium or plutonium.

Becquerel (Bq)
A unit of radiation equal to one disintegration per second.

Beta Particle
A particle emitted from an atom during radioactive decay.

Biological Shield
A mass of absorbing material (e.g., thick concrete walls) placed around a reactor or radioactive material to reduce the radiation (especially neutrons and gamma rays respectively) to a level safe for humans.

Breed
To form fissile nuclei, usually as a result of neutron capture, possibly followed by radioactive decay.

Chain Reaction
A reaction that stimulates its own repetition, in particular where the neutrons originating from nuclear fission cause an ongoing series of fission reactions.

Containment Building
A containment building houses the reactor, pressurizer, reactor coolant pumps, steam generator and other equipment or piping containing reactor coolant. The containment building is an airtight structure made of steel-reinforced concrete.

Control Rods
Devices to absorb neutrons so that the chain reaction in a reactor core may be slowed or stopped.

Coolant
This is a fluid, usually water, circulated through the core of a nuclear power reactor to remove and transfer heat energy.

Core
The central part of a nuclear reactor containing the fuel elements and any moderator.

Critical Mass
The smallest mass of fissile material that will support a self-sustaining chain reaction under specified conditions.

Curie (Ci)
A unit of radiation measurement, equal to 3.7x1010 disintegrations per second.

Decay
Decrease in activity of a radioactive substance due to the disintegration of an atomic nucleus resulting in the release of alpha or beta particles or gamma radiation.

Decommissioning
Removal of a facility (e.g., reactor) from service, also the subsequent actions of safe storage, dismantling and and making the site available for unrestricted use.

Depleted Uranium
Uranium having less than the natural 0.7% U-235. As a by-product of enrichment in the fuel cycle it generally has 0.25-0.30% U-235, the rest being U-238. Can be blended with highly-enriched uranium (e.g., from weapons) to make reactor fuel.

Deuterium
"Heavy Hydrogen", an isotope having one proton and one neutron in the nucleus. It occurs in nature as 1 atom to 6,500 atoms of normal hydrogen, (Hydrogen atoms contain one proton and no neutrons).

Dose Equivalent
The absolute measurement of exposure to a dose of ionising radiation depends upon the type of particle and the body tissue with which it interacts - hence the conversion to *dose equivalent*, which has units of rem. Rads are converted to rems by multiplying by a factor that depends upon the type of ionising radiation and it's biological effect. For example, with gamma radiation the factor is 1 and a rad is equal to a rem.

Element
A chemical substance that cannot be divided into simple substances by chemical means; atomic species with same number of protons.

Enriched Uranium
Uranium in which the proportion of U-235 (to U-238) has been increased above the natural 0.7%. Reactor-grade uranium is usually enriched to about 3.5% U-235, weapons-grade uranium is more than 90% U-235.

Enrichment
Physical process of increasing the proportion of U-235 to U-238.

Fast Breeder Reactor (FBR)
A fast neutron reactor (qv) configured to produce more fissile material than it consumes, using fertile material such as depleted uranium.

Fast Neutron Reactor (FNR)
A reactor with little or no moderator and hence utilising fast neutrons and able to utilise fertile material such as depleted uranium.

Fertile (of an isotope)
Capable of becoming fissile, by capturing one or more neutrons, possibly followed by radioactive decay. U-238 is an example.

Fissile (of an isotope)
Capable of capturing a neutron and undergoing nuclear fission, e.g., U-235, Pu-239.

Fission
The splitting of a heavy nucleus into two, accompanied by the release of a relatively large amount of heat and generally one or more neutrons. It may be spontaneous but usually is due to a nucleus absorbing a neutron.

Fission Products
Daughter nuclei resulting either from the fission of heavy elements such as uranium, or the radioactive decay of those primary daughters. Usually highly radioactive.

Fuel Assemblies
These are a group of fuel rods.

Fuel Fabrication
Making reactor fuel elements.

Gamma Rays
High energy electro-magnetic radiation.

Graphite
A form of carbon used in a very pure form as a reactor moderator.

Half-Life
The period required for half of the atoms of a particular radioactive isotope to decay and become an isotope of another element.

Heavy Water
Water containing an elevated concentration of molecules with deuterium ("heavy hydrogen") atoms.

Heavy Water Reactor (HWR)
A reactor which uses heavy water as its moderator.

High-Level Wastes
Extremely radioactive fission products and transuranic elements (usually other than plutonium) separated as a result of reprocessing spent nuclear fuel.

Highly (or High)-Enriched Uranium (HEU)
Uranium enriched to at least 20% U-235. Uranium in weapons is about 90% U-235.

Isotope
An atomic form of an element having a particular number of neutrons. Different isotopes of an element have the same number of protons but different numbers of neutrons and hence different atomic masses, e.g., U-235, U-238.

Joule
A unit of energy.

KeV
One thousand electron-volts. An electronvolt (symbol: eV) is the amount of energy gained by a single unbound electron when it falls through an electrostatic potential difference of one volt. This is a very small amount of energy.

Kilowatt
A Kilowatt is a unit of electric energy equal to 1,000 watts.

Kilowatt-Hour
This is a unit of energy consumption that equals 1,000 watts used for one hour. For example, ten 100-watt light bulbs burned for one hour use one kilowatt-hour of electricity.

Lattice
Structural configuration in a reactor organizing positioning of fuel rods, control rods, and safety rods.

Light Water
Ordinary water (H20) as distinct from heavy water.

Light Water Reactor (LWR)
A common nuclear reactor cooled and usually moderated by ordinary water.

Low-Enriched Uranium (LEU)
Uranium enriched to less than 20% U-235. Uranium in power reactors is about 3.5% U-235.

Megawatt (MW)
A unit of power, = 10^6 Watts. MWe refers to electric output from a generator, MWt to thermal output from a reactor or heat source (e.g., the gross heat output of a reactor itself, typically three times the MWe figure).

Metal Fuels
Natural uranium metal as used in a gas-cooled reactor.

Micro
One millionth of a unit (e.g., microsievert is one millionth of a Sv).

Millirem
This is a measurement of the biological effects of different types of radiation equaling 1/1000th of a REM.

Mixed Oxide Fuel (MOX)
Reactor fuel which consists of both uranium and plutonium oxides, usually with about 5% Pu.

Moderator
A material such as light or heavy water or graphite used in a reactor to slow down fast neutrons so as to expedite further fission.

Natural Uranium
Uranium with an isotopic composition as found in nature, containing 99.3% U-238, 0.7% U-235 and a trace of U-234.

Neutron
An uncharged elementary particle found in the nucleus of every atom except hydrogen. Solitary mobile neutrons travelling at various speeds originate from fission reactions. Slow neutrons can in turn readily cause fission in atoms of some isotopes, e.g., U-235, and fast neutrons can readily cause fission in atoms of others, e.g., Pu-239. Sometimes atomic nuclei simply capture neutrons.

Nuclear Reactor
A device in which a nuclear fission chain reaction occurs under controlled conditions so that the heat yield can be harnessed or the neutron beams utilised. All commercial reactors are thermal reactors, using a moderator to slow down the neutrons.

Oxide Fuels
Enriched or natural uranium in the form of the oxide U02, used in many types of reactor.

Plutonium
A transuranic element, formed in a nuclear reactor by neutron capture. It has several isotopes, some of which are fissile and some of which undergo spontaneous fission, releasing neutrons. Weapons-grade plutonium is produced with >90% Pu-239, reactor-grade plutonium contains about 30% non-fissile isotopes.

Pressurised Water Reactor (PWR)
The most common type of light water reactor (LWR).

Radiation
The emission and propagation of energy by means of electromagnetic waves or sub-atomic particles.

Radioactivity
The spontaneous decay of an unstable atomic nucleus, giving rise to the emission of radiation.

Radionuclide
A radioactive isotope of an element.

Radiotoxicity
The adverse health effect of a radionuclide due to its radioactivity.

rads
A unit to measure the absorption of radiation by the body. A rad is equivalent to 100 ergs of energy from ionising radiation absorbed per gram of soft tissue.

Reactor Vessel
It is the steel pressure vessel that holds the fuel elements in a reactor.

rem (Roentgen Equivalent Man)
REM is the common unit for measuring human radiation doses, usually in millirems (1,000 millirems = 1 rem).

Reprocessing
Chemical treatment of spent reactor fuel to separate uranium and plutonium from the small quantitiy of fission products (and from each other), leaving a much reduced quantity of high-level waste.

Shielding
Material, such as lead or concrete, that is used around a nuclear reactor to prevent the escape of radiation and to protect workers and equipment.

Spent Fuel
This is used nuclear fuel awaiting disposal.

Stable
Incapable of spontaneous radioactive decay.

Thermal Reactor
A reactor in which the fission chain reaction is sustained primarily by slow neutrons (as distinct from Fast Neutron Reactor).

Transuranic Element
A very heavy element formed artificially by neutron capture and subsequent beta decay(s). Has a higher atomic number than uranium (92). All are radioactive. Neptunium, plutonium and americium are the best-known.

Uranium
A mildly radioactive element with two isotopes which are fissile (U-235 and U-233) and two which are fertile (U-238 and U-234). Uranium is the basic raw material of nuclear energy.

Uranium Oxide Concentrate (U308)
The mixture of uranium oxides produced after milling uranium ore from a mine. Sometimes loosely called yellowcake. It is khaki in colour and is usually represented by the empirical formula U308. Uranium is exported from Australia in this form.

Vitrification
The incorporation of high-level wastes into borosilicate glass, to make up about 14% of the product by mass.

Waste
High-level waste (HLW) is highly radioactive material arising from nuclear fission. It is recovered from reprocessing spent fuel, though some countries regard spent fuel itself as HLW and plan to dispose of it in that form. It requires very careful handling, storage and disposal.

Waste
Low-level waste is mildly radioactive material usually disposed of by incineration and burial.

Yellowcake
Ammonium diuranate, the penultimate uranium compound in U308 production, but the form in which mine product was sold until about 1970.

Sources Used:
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